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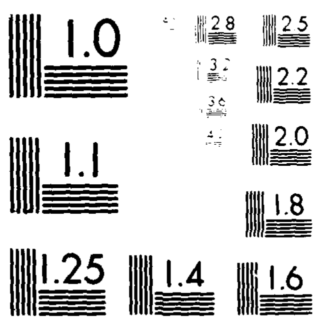

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FAULTS AND LINEAMENTS IN THE
MX SITING REGION, NEVADA AND UTAH

VOLUME I

Prepared for:

U.S. Department of the Air Force
Ballistic Missile Office
Norton Air Force Base, California 92409

Prepared by:

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6 November 1981

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Results of the fault study in Nevada and Utah show that all valleys in the MX deployment area have faults that have been active in Quaternary time. Earthquakes in the 7-7 3/4 magnitude have occurred in the study area during late Quaternary time. Quaternary faults trend North-south and are parallel to the regional Basin and Range [illegible]

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FOREWORD

This report was prepared for the U.S. Department of the Air Force, Ballistic Missile Office (BMO), in compliance with Contract No. F04704-80-C-0006. The major objective of this investigation was to determine the nature and extent of faults and lineaments in the areas proposed for the MX facilities in Nevada and Utah to determine whether there is a potential hazard from earthquakes or fault rupture and to quantify such hazards.

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VOLUME II

EXECUTIVE SUMMARY

Studies to evaluate fault and earthquake hazards for the MX missile system were conducted within an area of about 40,000 mi^2 (60,000 km^2) in east-central Nevada and west-central Utah. These studies consisted primarily of analysis of color, stereo aerial photographs of 1:25,000 scale for faults and lineaments, and follow up geologic field reconnaissance of the suspected faults and lineaments. The primary goals of these investigations were to determine the location, nature, and age of last movement on the faults and lineaments and to evaluate the size, frequency, and potential for future earthquakes.

The valleys comprising the fault-study region are within the Central Great Basin and Southern Nevada seismotectonic provinces of the Basin and Range physiographic province. This area is characterized by northerly to north-northeasterly striking mountain ranges and valleys. These mountains and valleys are generally horst and graben and (or) tilt-block geologic structures that are separated by high-angle, down-to-basin, normal faults formed by late-Cenozoic Basin and Range crustal extension. This extensional tectonic regime is still in effect as indicated by the earthquakes and abundant late Quaternary normal faults in the region.

Late Quaternary faults and lineaments suspected of being fault related occur in every valley studied. These faults are

strongly oriented in northerly and north-northeasterly directions subparallel to the regional Basin and Range structural fabric. Fault displacements are almost exclusively of a normal dip-slip type with no large components of lateral slip observed. Regional structural lineament systems cross the study area with east-west, northwest-southeast, and northeast-southwest trends, but these features are not presently active and do not represent a major factor in the earthquake and fault-rupture hazards assessment.

Most valleys have one major Quaternary block-bounding fault along one margin and numerous other smaller Quaternary faults scattered throughout the valley. Most of these faults last ruptured during the late Quaternary Period (about the last 200,000 years). Several faults have ruptured the surface since late Pleistocene glacial lakes have dried up and thus may be as young as Holocene. Lineaments of suspected fault origin are common throughout the study region indicating that the mapped faults are probably only a minimum representation of the fault-rupture hazard. The lengths of the major faults and the amount of surface displacements suggest that earthquakes as large as magnitude 7 to 7 3/4 are possible even though only small magnitudes (generally less than about magnitude 5) have been reported during historic time. The time interval between the large earthquakes is long, averaging on the order of 15,000 years or more, hence the probability of such an earthquake occurring in the MX deployment region during the relatively short life of the system is remote.

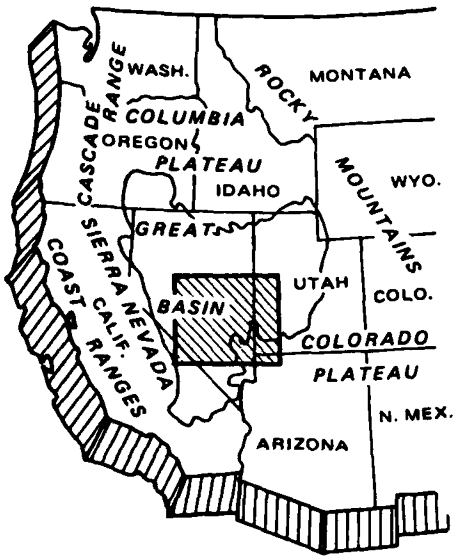
1.0 INTRODUCTION

1.1 PURPOSE OF INVESTIGATION

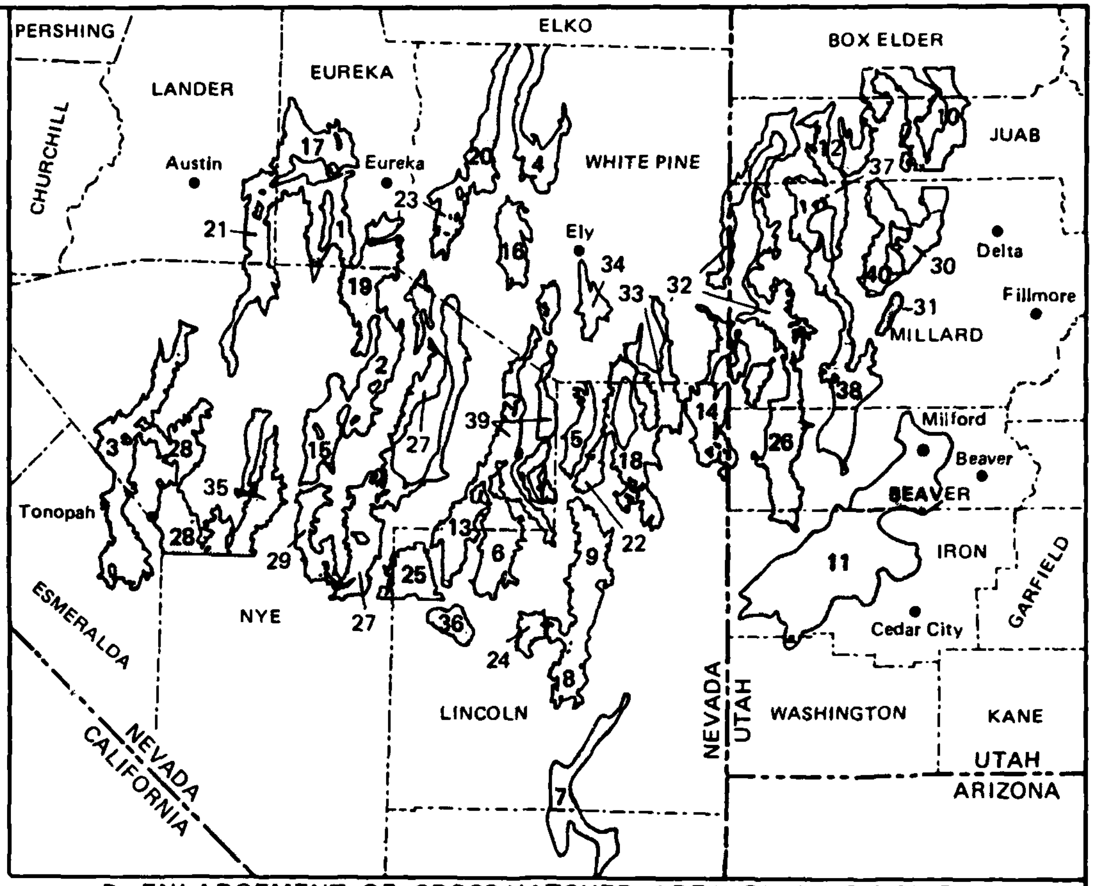
This investigation, started in 1979, is part of geotechnical Verification studies which are the final phase of a site-selection process begun in 1977. The major objective of the Verification studies is to define areas suitable for deployment of the MX system.

The purpose of this report is to provide a summary of information on faults for use in the deployment, engineering, and construction of the MX missile system in Nevada and Utah (Figure 1). Additional information on faults is available in the Verification reports for each valley.

Data discussed within this report have been used in other on-going, MX-related siting studies. Gravity studies have utilized fault-study maps to assist in profiling and contouring of the subsurface geologic structure of the valleys. Hydrology studies have used fault-study data to assist in subsurface contouring of ground-water tables and determination of geologic structure that may affect the hydrology of a valley. The MX Mineral Resources Study applied fault and lineament data to help define areas of shallow alluvial fill and tectonic patterns that may indicate favorable mineral potential. Verification, Operational Base, and Shelter Layout studies used fault and lineament data to assist in determining suitable siting areas for MX facilities.



A. INDEX MAP SHOWING LOCATION OF FAULT STUDY AREA AND MAJOR PHYSIOGRAPHIC PROVINCES.



B. ENLARGEMENT OF CROSS-HATCHED AREA ON INDEX MAP. SHADED AREAS REPRESENT VALLEYS STUDIED IN DETAIL; NAMES OF VALLEYS LISTED BELOW.

1. ANTELOPE VALLEY
2. BIG SAND SPRINGS VALLEY
3. BIG SMOKY VALLEY
4. BUTTE VALLEY
5. CAVE VALLEY
6. COAL VALLEY
7. COYOTE-KANE VALLEY
8. DELAMAR VALLEY
9. DRY LAKE VALLEY
10. DUGWAY VALLEY
11. ESCALANTE DESERT
12. FISH SPRINGS FLAT
13. GARDEN VALLEY
14. HAMLIN VALLEY
15. HOT CREEK VALLEY
16. JAKES VALLEY
17. KOBEH VALLEY
18. LAKE VALLEY
19. LITTLE SMOKY VALLEY
20. LONG VALLEY
21. MONITOR VALLEY
22. MULESHOE VALLEY
23. NEWARK VALLEY
24. PAHROC VALLEY
25. PENOYER (SAND SPRING VALLEY)
26. PINE VALLEY
27. RAILROAD VALLEY
28. RALSTON VALLEY
29. REVEILLE VALLEY
30. SEVIER DESERT
31. SEVIER LAKE
32. SNAKE VALLEY
33. SPRING VALLEY
34. STEPTOE VALLEY
35. STONE CABIN VALLEY
36. TIKABOO VALLEY
37. TULE VALLEY
38. WAH WAH VALLEY
39. WHITE RIVER VALLEY
40. WHIRLWIND VALLEY

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AREAS STUDIED WITHIN THE NEVADA-UTAH MX DEPLOYMENT REGION

FIGURE 1

1.2 SCOPE OF INVESTIGATION

The primary tasks of the investigation were:

1. Identification of the locations of young faults;
2. Evaluation of their age of most recent movement;
3. Determination of the nature and amount of surface rupture;
4. Evaluation of how often surface rupture has occurred; and
5. Evaluation of the potential for future rupture.

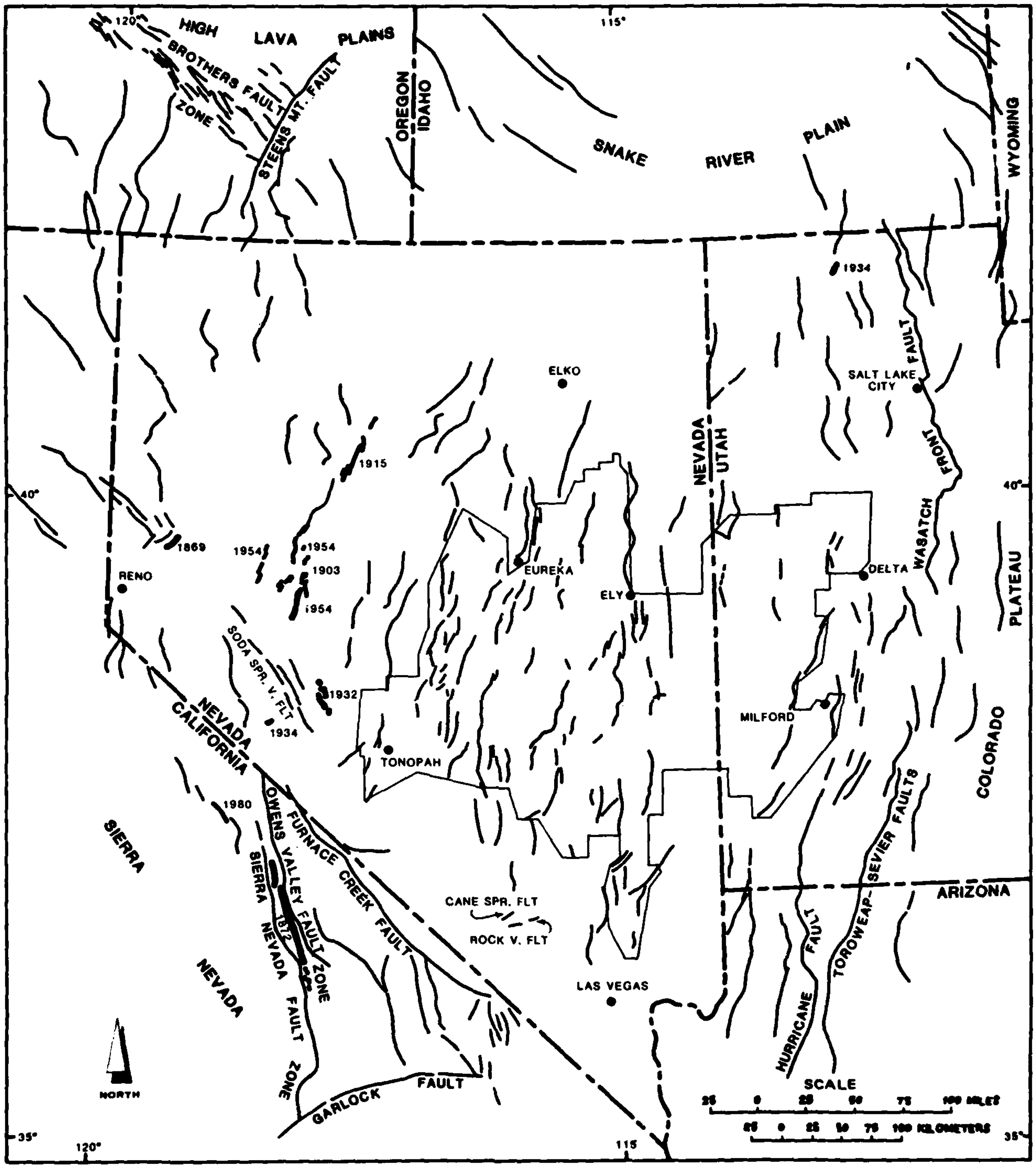
These tasks were accomplished by review of literature, analysis of aerial photographs, field checking, and geophysical surveys.

This investigation is a continuation of the investigation described in the "Interim Report on Active Faults and Earthquake Hazards in the FY 79 Verification Sites, Nevada-Utah Siting Region" (Fugro National, Inc., 1980a). The previous report described seismicity, regional tectonics, Quaternary faulting, and possible criteria for deployment of MX facilities. The discussion of faulting in that report was based on literature review and preliminary analysis of aerial photographs. This report describes field and geophysical methods and presents the final results of the fault and lineament study.

2.0 SEISMOTECTONIC SETTING

2.1 REGIONAL TECTONICS

The valleys comprising the Nevada-Utah MX deployment area are within the Great Basin section of the Basin and Range physiographic province (Figure 1). The name Great Basin refers to the physiographic region where most stream drainage is into the valleys with no outlet to the sea. Contrary to the implication of the name, the Great Basin is topographically high, the result of regional late Cenozoic uplift (Stewart, 1978). Physiographically, the Great Basin is characterized by northerly to northeasterly trending, linear, subparallel mountain ranges and valleys which are a result of late-Cenozoic crustal tension and uplift. Structurally, the basins and ranges are horst and graben and (or) tilt-block geologic structures separated by high-angle, down-to-the-basin, normal faults. The larger Basin and Range province extends from Oregon and Idaho on the north, southward to about Guaymas, Mexico, and from the Sierra Nevada Mountains on the west, to the Colorado Plateau on the east (Figure 2). The Great Basin section can be distinguished from most of the other sections of the Basin and Range province on the basis of its more rugged physiography, prominent northerly to north-northeasterly oriented fault trends, earthquake frequency and distribution, heat flow, crustal thickness, and crustal P-wave speeds (Schell and Hileman, 1979).



EXPLANATION

1872 Fault with historic surface rupture and date of most recent major earthquake

Major young fault

Boundary of Nevada-Utah MX fault-study region

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MAJOR FAULTS IN THE VICINITY OF THE MX FAULT–STUDY REGION AND HISTORIC SURFACE RUPTURES

FIGURE 2

Geologically, the Great Basin section is bounded on the north by late Tertiary volcanic plains in Oregon and Idaho and on the west by the Mesozoic batholiths of the Sierra Nevada mountain range. The eastern boundary of the province is along the edge of the Colorado Plateau and the middle Rocky Mountains. This boundary is transitional with the interior of the Great Basin but is more intensely broken by young faults than most of the interior. It is characterized by a relatively high rate of earthquake activity (the Intermountain Seismic Belt of Smith and Sbar, 1974) and a relative profusion of Quaternary basaltic volcanics. The southern boundary of the Great Basin lies within the northern Mojave and Sonoran deserts.

The pre-Cenozoic tectonic history of the Great Basin was primarily one of compressional tectonic events which resulted in the formation of large allochthonous thrust sheets such as the Roberts Mountain thrust, the Golconda thrust, and the Keystone thrust. Five major compressional episodes have been identified; the Antler, Sonoma, Nevadan, Sevier, and Laramide orogenies.

During the Cenozoic, the Great Basin experienced two major stages of volcanic and tectonic development. During the early Tertiary (about 43 to 17 million years ago), the entire area experienced predominantly calc-alkalic volcanism of intermediate to silicic composition (McKee and others, 1970; Lipman and others, 1972; and Stewart and Carlson, 1976). This early Tertiary volcanism was probably related to subduction of the ancient Farallon plate under the North American plate west of the study area (Atwater, 1970; and Atwater and Molnar, 1973).

A brief lull in volcanism occurred in Miocene time (between about 19 to 17 million years ago) and was followed by predominantly basaltic or bimodal rhyolite-basalt volcanism (Christiansen and Lipman, 1972; Stewart and Carlson, 1976; and Christiansen and McKee, 1978).

About 17 to 14 million years ago, the pattern of subparallel fault-bounded linear ranges and alluvial basins typical of the present Great Basin region began to form. Volcanism within the central part of the Great Basin province was limited and widely scattered during the earlier part of this block-faulting tectonic episode (17 to 6 million years ago). Pliocene and Quaternary volcanism was even less prominent and was restricted primarily to the perimeter of the central Great Basin. Within the central part of the Great Basin, Quaternary basalts are rare and occur only in the Lunar Crater volcanic center near the Hot Creek, Reveille, and Railroad Valley deployment areas, near the eastern border in the Sevier Desert area, and in northern Lander and southern Humboldt counties north of the study area.

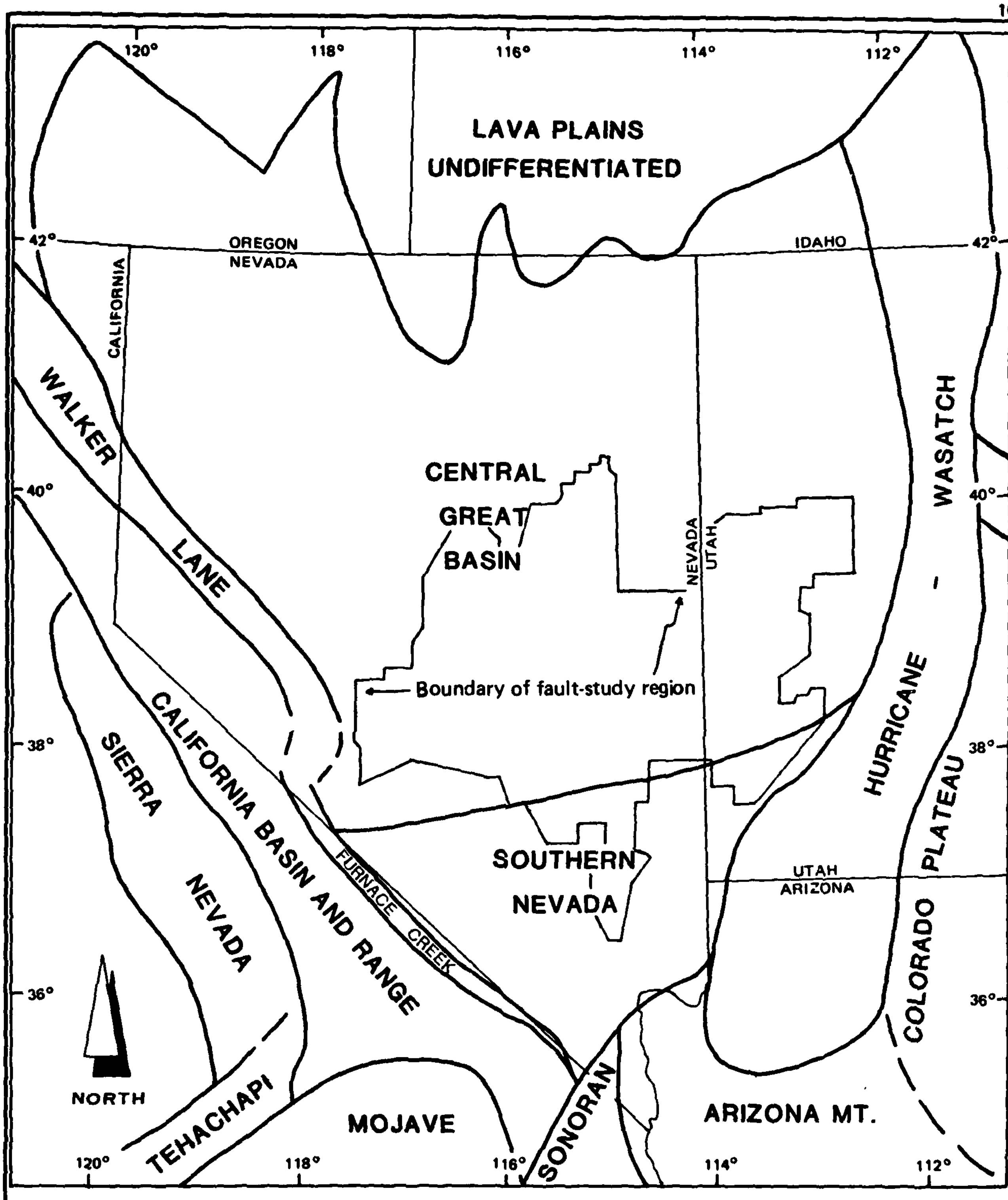
Although the Basin and Range block faulting began about 17 to 14 million years ago, the large sedimentary basins typical of the province today were not well developed until about 13 to 11 million years ago and did not reach their present degree of development until very late Miocene about 7.5 million years ago (Stewart, 1978).

Extension across individual grabens within the Great Basin averages about 1.5 miles (2.4 km), and total extension across the Basin and Range is estimated at 30 to 60 miles (50 to 100 km) (Hamilton and Myers, 1966; Stewart, 1971; and Thompson and Burke, 1974). Extension rates on the order of 0.2 to 0.8 inch (0.5 to 2 cm) per year have been estimated for the late Cenozoic (Stewart, 1971; Thompson and Burke, 1974; Slemmons and others, 1979; and Wallace, 1979).

The basins and ranges produced by the late Cenozoic normal faulting form relatively simple structural patterns at the surface. They appear to be more complex at depth and the mechanics of their formation is not well understood. Three basic models of Basin and Range block-faulted structure have been proposed (Stewart, 1971 and 1978). In all of these models, the mountains are the uplifted blocks and the valleys are the down-dropped blocks. One model relates Basin and Range structure to a system of structural blocks rotated along curving, downward flattening faults (listric faults). The second model relates Basin and Range structure to a system of horsts and grabens in which mountain-forming horsts and valley-forming grabens are separated by relatively constantly dipping normal faults. The third model relates the structure to a system of elongate rhombohedral blocks.

In spite of the similarity of physiography and geologic structure throughout the Great Basin section, certain young tectonic data (neotectonic) allow subdivision into a number of seismotectonic provinces (Figure 3). These seismotectonic provinces include the Central Great Basin, the California Basin and Range, the Southern Nevada, the Walker Lake-Furnace Creek, the Hurricane-Wasatch, the Mojave, the Sonoran, and the Arizona Mountain provinces (see Schell; 1978, Greensfelder and others, 1980; and Schell and Wilson, 1981). The Central Great Basin, Hurricane-Wasatch, Walker Lane-Furnace Creek, and Southern Nevada provinces are of special interest to this study because of their proximity to the study area.

The boundary between the Central Great Basin province and the California Basin and Range province is the Walker Lane-Furnace Creek province, a zone of late Cenozoic, right-lateral faults and topographic basins. This zone extends from northeastern California through northwestern Nevada to near the southern terminus of Big Smoky Valley. Near the southern end of Big Smoky Valley, numerous faults assume general east-west trends suggesting a discontinuity in the southeasterly trending lateral faulting of the Walker Lane. Further to the west, however, right-lateral displacement is prominent within the Furnace Creek shear zone. Together, the Walker Lane and the Furnace Creek zones form a northwesterly-southeasterly trending zone about 15 miles (25 km) wide between northeasterly trending faults in the Central Great Basin and Southern Nevada provinces and the northwesterly trending faults within the California



SCALE

25 0 50 100 MILES

25 0 50 100 KILOMETERS

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SEISMOTECTONIC PROVINCE MAP
OF THE GREAT BASIN REGION

FIGURE 3

Basin and Range province (Figures 2 and 3). Except for the Dixie Valley-Pleasant Valley seismic zone, earthquake activity and volcanism appear to be more frequent west of the Walker Lane-Furnace Creek zone and are the primary basis for separation of this area into a separate seismotectonic province (Schell, 1978; Schell and Hileman, 1979; Vanwormer and Ryall, 1980; Greensfelder and others, 1980; and Schell and Wilson, 1981).

A less well-known zone with possible late Cenozoic lateral faulting, the southern Nevada seismotectonic province, extends across the southern part of Nevada (Figure 3). This zone includes the Pahranagat Shear Zone, described by Tschanz and Pampeyan (1970), which extends from the southern end of Delamar Valley to the northern end of Desert Valley (see Section 4.3.3).

2.2 REGIONAL SEISMICITY

Regional Worldwide Standardized Seismographic Network instrumental earthquake data for the siting region are cataloged by the U.S. Geological Survey. In addition to the regional coverage, local seismograph networks are operated by the U.S. Geological Survey for the area around the Nevada Test Site, by the University of Nevada at Reno for the northwestern part of Nevada, and by the University of Utah for most of the western Utah. A detailed discussion of the seismicity is presented in the Interim Fault Report (Fugro National, Inc., 1980a).

In summary, earthquake activity in the study region is characterized by a low rate of activity with most earthquakes being in the 3 to 4 magnitude range. The largest earthquake in the vicinity of the study region was the 6.1 magnitude event of 16 August 1966 which occurred in the Clover Mountains southeast of the study area near the Nevada-Utah border. With the exception of a few weak clusters of earthquake activity, seismicity in the study region is widely scattered. Clusters of earthquake activity have occurred near Eureka, within the Snake Range, and in the southern Delamar Mountains. Aerial photograph analysis and reconnaissance field checking did not reveal any surface rupturing which could be attributed to these minor seismic disturbances. A large cluster of events in southwestern Nevada represent numerous underground nuclear explosions in the Nevada Test Site.

Table 1 lists the major historic earthquakes within the Great Basin region. In areas adjacent to the study region, two zones of earthquake activity are recognized, the Intermountain Seismic Belt and the Dixie Valley-Pleasant Valley zone. The Intermountain Seismic Belt is a zone of pronounced earthquake activity, 120 miles (90 km) wide, extending along the eastern margin of the Basin and Range province from Arizona through Utah, eastern Idaho and western Wyoming, and ending in northwestern Montana (Smith and Sbar, 1974). Along the eastern edge of the Great Basin, this belt of seismicity coincides with the Hurricane-Wasatch seismotectonic province (Schell, 1978). The Intermountain Seismic Belt bifurcates at its southern end with

TABLE 1

MAJOR HISTORIC EARTHQUAKES ADJACENT TO THE NEVADA-UTAH MX SITING REGION

DATE		MAGNITUDE	AREA	MAXIMUM DISPLACEMENT(2) ft (m)	LENGTH OF SURFACE RUPTURE(2) mi (km)
	1847	-	West-Central Utah	None Known	None Known
28 December	1869	6.7(1)	Olinghouse, Nevada	12 (3.6)	14 (23)
26 March	1872	8.0(1)	Owens Valley, CA	21 (6.4)	68 (110)
5 December	1887	5.7(1)	Kanab, Utah	None Known	None Known
17 November	1902	6.3(1)	Pine Valley, Utah	None Known	None Known
Autumn	1903		Wonder, Nevada	1 (0.3)	12 (19)
2 October	1915	7.6	Pleasant Valley, Nevada	18 (5.6)	36 (58)
21 December	1932	7.2	Cedar Mountain, Nevada	3 (0.9)	38 (61)
30 January	1934	6.3	Excelsior Mountain, Nevada	0.3 (0.1)	>1 (>1.6)
12 March	1934	6.6	Hansel Valley, Utah	1.6 (0.5)	3.3 (5.2)
6 July	1954	6.8	Rainbow Mountain, Nevada	1 (0.3)	20 (32)
24 August	1954	6.8	Fallon-Stillwater, Nevada	2.6 (0.8)	19 (31)
16 December	1954	7.2	Fairview Peak, Nevada	18 (5.6)	55 (88)
16 December	1954	7.1	Dixie Valley, Nevada	10 (3.2)	38 (61)
23 March	1959	6.3	Dixie Valley, Nevada	0	0
21 July	1959	5.7	Kanab, Utah	0	0
16 August	1966	6.1	Clover Mountain, Nevada	0	0

(1) Estimated magnitude for earthquakes occurring before establishment of seismograph networks.

(2) Surface ruptures and surface displacement may have been associated with preinstrumental earthquakes and not have been reported; these are listed as "none known"; recent earthquakes which probably had no surface expression are listed as 0.

zones of lesser seismicity extending southwestward from south-central Utah across southern Nevada and coinciding with the northern part of the Southern Nevada seismotectonic province and the other extending southward and southeastward through Arizona coinciding with the Arizona Mountain seismotectonic province (see Figure 3).

The Dixie Valley-Pleasant Valley seismicity zone lies immediately west and northwest of the fault-study region and consists of a north-south alignment of earthquake activity and surface ruptures in western Nevada extending from the southern Walker Lane zone (Soda Springs Valley fault) through Pleasant Valley (the site of the 1915 rupture) in northern Nevada (Figure 2).

3.0 INVESTIGATIONS PERFORMED

3.1 AERIAL PHOTOGRAPH ANALYSIS

Aerial photograph analysis was conducted primarily on natural color, stereo-pair photographs at a scale of about 1:25,000. These photographs were taken by Ertec Airborne Systems during the fall 1978, summer 1979, and fall 1980.

Complete coverage of the study area is also provided by black and white stereo photographs at a scale of about 1:60,000. These photographs were taken by various agencies and are available from the U. S. Geological Survey-EROS.

The fault study concentrated on the alluvial valleys designated as siting areas but also included portions of mountain areas and continuations of the valleys beyond the limits of the designated siting areas. If the mountain area between adjacent siting areas was narrow, on the order of 5 miles (8 km) or less, the entire mountain region was analyzed, but only the margins of wider mountain ranges were analyzed. The rough terrain and vegetation in some mountains make fault identification difficult, and there may be young faults in these areas which were not recognized and are not shown on the maps (Plates A1 through A11).

Prior to the geologic field reconnaissance phase, the locations of faults and lineaments were transferred from aerial photographs to topographic maps at scales of 1:62,500. These topographic base maps were compiled from available U. S. Geological Survey 7.5 and 15 minute topographic quadrangles and, where topographic maps were not available, from aerial photographs. The aerial-photograph features were plotted on the base maps by matching topography and measuring from well-located, conspicuous geomorphic features or man-made features such as road intersections. Precision of this transfer process is estimated to be within about 0.1 inch (0.25 cm) which corresponds to a distance of about 528 feet (160 m). These data were transferred to the 1:250,000-scale maps (Appendix A, Plates A1 through A11) by photographic reduction.

3.2 GRAVITY ANALYSIS

Gravity data, supplied by the Defense Mapping Agency, were analyzed to develop models of the basin configuration. The results of the gravity studies have been integrated with the results of this fault study to provide insight into the deep buried structure of the valleys (see Section 4.2).

The block-faulted nature of the Great Basin with its alternating linear mountain ranges and alluvial-filled valleys results in large density contrasts between the basin-fill and the bedrock exposed in the ranges. These density contrasts yield linear gravity anomalies which clearly delimit the fault-block structures.

3.3 GROUND MAGNETOMETER ANALYSIS

Limited magnetometer surveys were conducted as one means of assessing whether aerial-photograph linears are fault related.

A few profiles were also measured across known faults to gain better understanding of the response of the magnetometer under various conditions in the siting area. The results of these studies are integrated into the interpretations of this report and are not reported separately.

3.4 GEOLOGIC RECONNAISSANCE

Field studies consisted of 1) verification of selected faults and lineaments, 2) ground magnetometer surveys, and 3) reconnaissance of historic fault ruptures. These field studies were done between March and November 1980.

On the final interpretation maps, from which Plates A1 through A11 are compiled, scarps were connected into more continous lines and represent a geologist's interpretation of fault continuity. Where only a few tens of feet of scarp is eroded away, the faults are interpreted as continuous and are drawn as solid lines. Some intervals between widely spaced scarps and areas at the ends of some scarps are marked by lineaments which suggest fault continuity; faulting in these areas is also interpreted as continuous but is more interpretive and, therefore, these are shown as dashed faults. Faulting in the siting region is commonly sinuous and en echelon and, in many cases, several faults are in close proximity. Interconnection of these faults were based on geological judgments. Although some errors are possible, they are minor and insignificant for siting purposes because faults in alluvium that are closely spaced most likely represent surface manifestations of one master fault at depth.

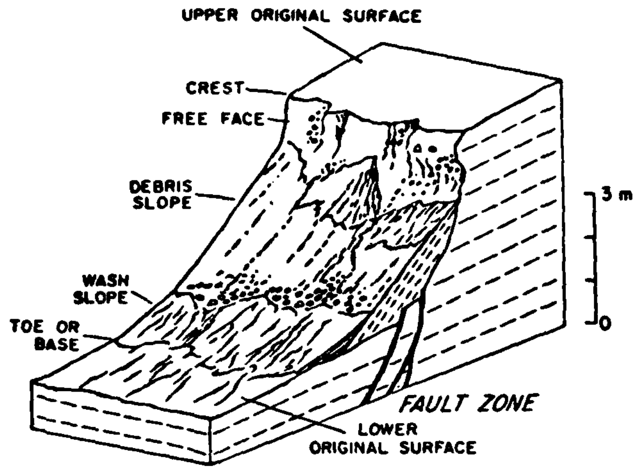
Field reconnaissance also included a study of historic fault ruptures to compare these known fault ruptures to features within the MX siting area. This reconnaissance included analysis of the areas studied by Wallace (1977, 1979) in Pershing, Eureka, and Lander counties, Nevada, and the Dixie Valley-Fairview Peak area in Churchill County, Nevada, the site of the 1954 earthquakes (Section 2.2).

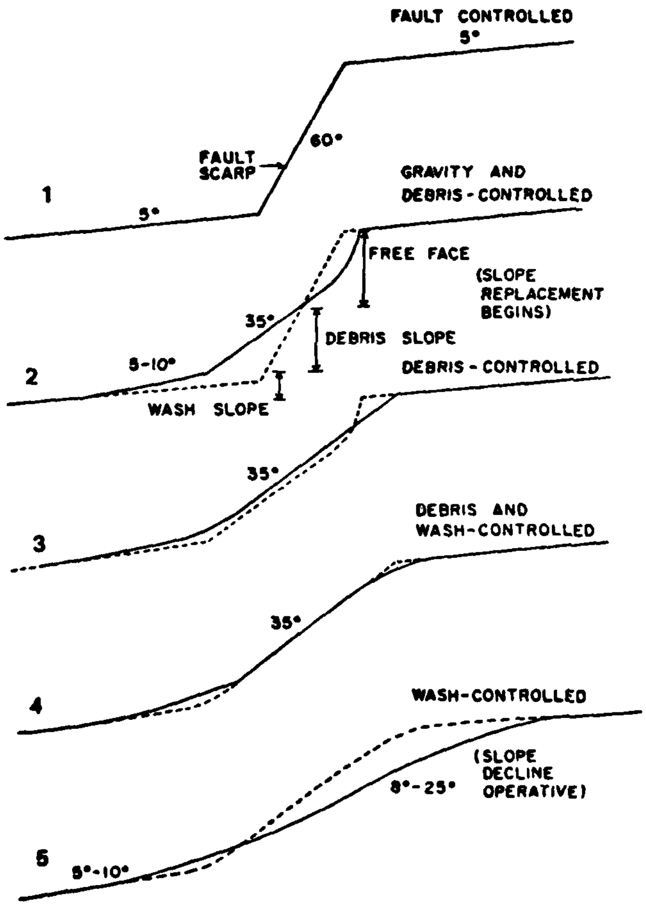
3.5 DETERMINATION OF FAULT AGES

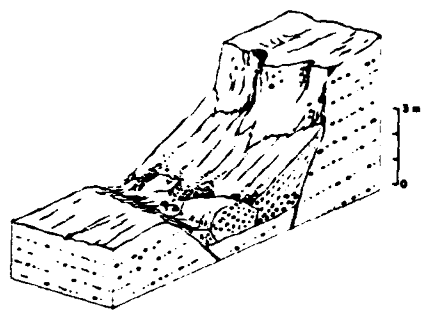
3.5.1 Fault-Scarp Morphology

Fault-scarp morphology was studied to determine the age of faulting according to criteria established by Wallace (1977) and refined by Dodge and Grose (1979) and Bucknam and Anderson (1979). During the field verification, a number of fault-scarp profile measurements and geomorphic observations were made. These were compared with each other and with the published data to help determine fault-scarp ages (Section 4.0). The premise of fault-scarp morphologic studies is that steep scarp-slope angles are younger than low-angle scarp slopes and that the time since the scarp formed can be estimated by comparing the slope-angle characteristics to scarps of known age. The important terms and the process of scarp decline are illustrated in Figure 4. Quantitative measurements of scarp height and slope angle and observations of crest sharpness, degree of scarp dissection, and the type and grain size of fan material are the important parameters in estimating scarp age. Other parameters such as slope of the original fan surface, position relative to

A– BLOCK DIAGRAM OF A FAULT SCARP SHOWING TERMINOLOGY USED IN THIS STUDY.







C–NORMAL FAULT SCARP WITH GRABEN.

B– SEQUENCE OF FAULT-SCARP DEGRADATION. PROFILES 1 THROUGH 5 SHOW INCREMENTAL CHANGE, DOTTED LINE REPRESENTS SOLID LINE OF PREVIOUS PROFILE.

from : Wallace, 1977

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FAULT SCARP TERMINOLOGY

FIGURE 4

the mountain fronts and playas, and climate may also be important. The complex interrelationships of the various parameters make it difficult to devise a model in which all the variables are included and correctly accounted for.

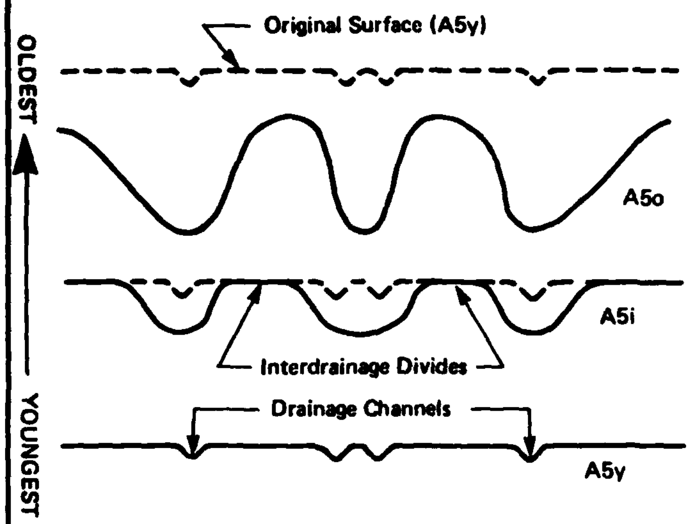
The major limitation of using fault-scarp morphology for dating faults is that the rates of the degradation process are poorly known. Furthermore, the rates appear to change as the process proceeds. Due to these limitations, not much reliance can be placed on scarp morphology alone but, combined with other data, probable ages of last movement can be approximated within broad categories such as Holocene, very late Pleistocene, late Pleistocene, middle Pleistocene, and early Pleistocene (Appendix A, Table A2).

3.5.2 Alluvial Fan Morphology

The majority of fault-age determinations in this study were based on the morphology of the alluvial fans displaced by the faults. Alluvial fans have been categorized into three basic age groups (young, intermediate, and old) based on the characteristics tabulated in Table 2 and diagrammed on Figure 5. The ages of these fan groups are based on cross-cutting relationships with features such as pluvial shorelines and regional correlation to alluvial fans with better defined ages based on absolute-age determinations. Table 3 gives the approximate age ranges of these fans and compares the terminology used in this study with that of similar studies in the southwestern United States.

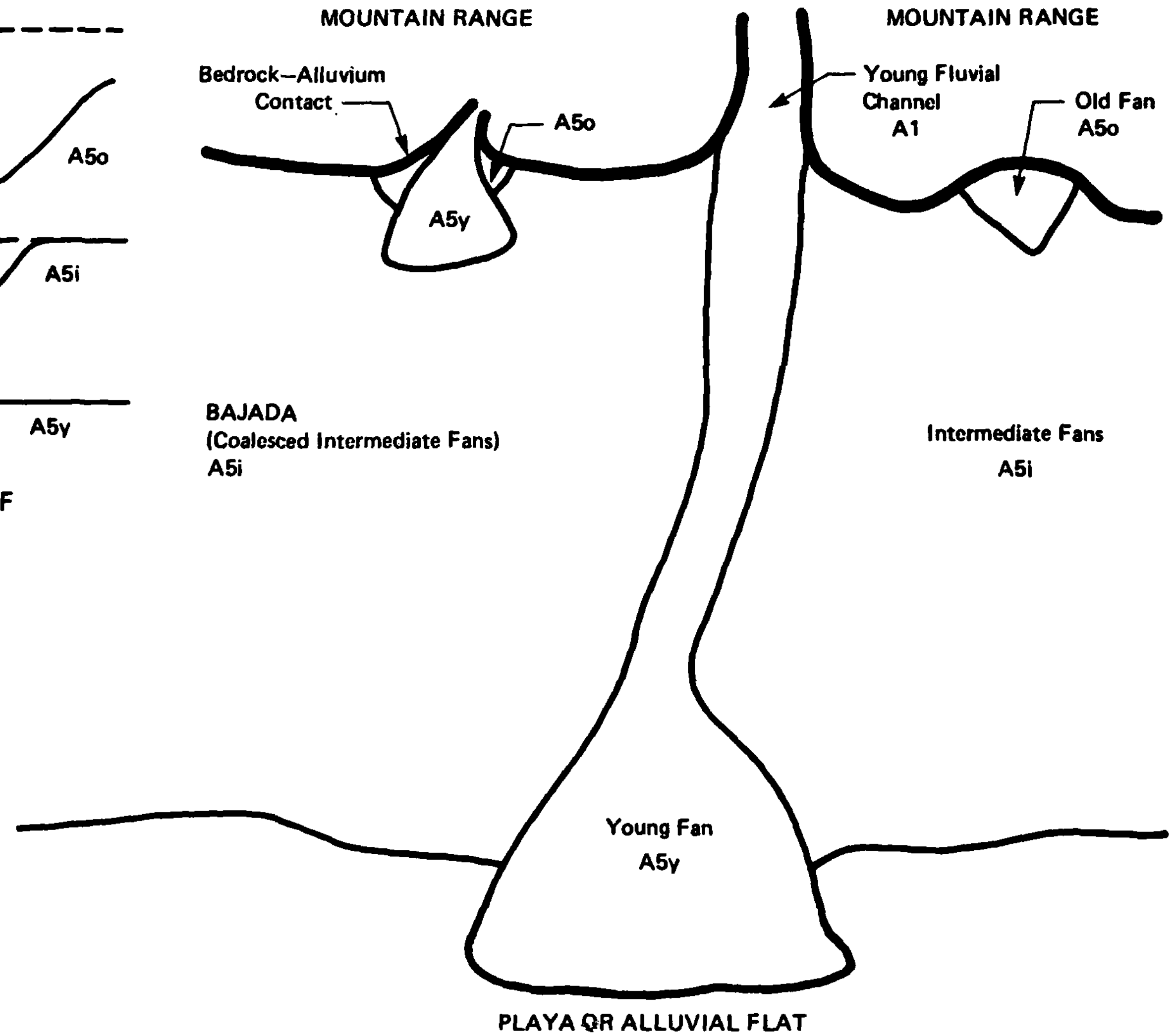
TABLE 2
CHARACTERISTICS OF ALLUVIAL FAN UNITS

	Youngest (A5y)	Intermediate (A5i)	Oldest (A5o)
Degree of Dissection	modern gullies and washes -- deep incision at fan apices active fans -- very slight (bar and channel topography)	slight to moderate (1 or 2 feet up to tens of feet)	completely dissected; divides destroyed; preserved in pediment passes and structural valleys within mountain ranges
Desert Pavement	slight development	moderate to well developed, easily discernible	typically destroyed by dissection, few remnants of divides
Desert Varnish (patina) (primarily on volcanics and metamorphics)	absent -- dark colored rocks usually reworked patinated clasts from bedrock or older surfaces	moderate to strong	strong where preserved; normally destroyed by dissection
Tone	light	dark (from varnished clasts)	light to medium (may have dark bands on divides)
Other	a) topographically lowest b) sinuous alignment of vegetation along drainages	a) most areally extensive surface b) not presently active c) divides well preserved	a) topographically highest b) well developed, complex drainage network
Caliche	Thin partial coatings on pebbles, think strings, disseminated throughout deposit	complete coatings up to 0.5 m inch thick, nodules, K-horizon up to 60 inches thick	K-horizon completely plugged, pebbles engulfed in rinds up to 1 inch thick, laminar accumulations



B. CROSS–SECTIONAL VIEW OF ALLUVIAL FANS.

NOTE: NOT TO SCALE



A. MAP VIEW

NOTE: NOT TO SCALE

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DIAGRAM OF RELATIONSHIPS
BETWEEN PRINCIPAL
GEOMORPHIC UNITS

FIGURE 5

TABLE 3

ESTIMATED AGES OF ALLUVIAL UNITS IN THE MX FAULT-STUDY REGION AND COMPARISON TO OTHER AGE CLASSIFICATIONS IN THE SOUTHWESTERN UNITED STATES

This Study		Shlemon and Purcell, 1976		San Diego Gas and Electric Co., 1976		Bull, 1974	
Estimated Ages (yrs)	Unit Designation	Estimated Ages (yrs)	Unit Designation	Estimated Ages (yrs)	Unit Designation	Estimated Ages (yrs)	Unit Designation
Modern	A1,A2,A3,A4	0	Q_1	0	Qa1	0	Q_4
0 to 15,000	A5y, A4o	0 to 15,000	Q_2	0 to 10,000	Qf	2,000	Q_3
15,000 to 700,000	A5i*	15,000 to 500,000-700,000	Q_3	30,000 to 100,000	Qfc	11,000 to 200,000	Q_2
700,000 to 1,800,000	A5o	>500,000	Q_4	500,000	QTfc Tf,QTfa	500,000 to >1,500,000	Q_1
>125,000	A6						

NOTE: *Although this unit theoretically covers all fans formed since the Brunhes-Matuyana magnetic reversal, most of the fans in the study region formed since the Illinoian glacial period and thus are less than about 200,000 years old.

The youngest fans, A5y, are areas of active aggradation with distinctive drainage patterns consisting of distributary channels that diverge from their sources. The A5y fans may be the lowest and farthest from the range front or may be at the mouths of channels emerging from the mountains and on top of preexisting intermediate or old fans (Figure 5A). Generally, A5y fans have well defined fan shapes. Figure 5B depicts a cross-sectional view of a fan as it evolves from A5y to A5o.

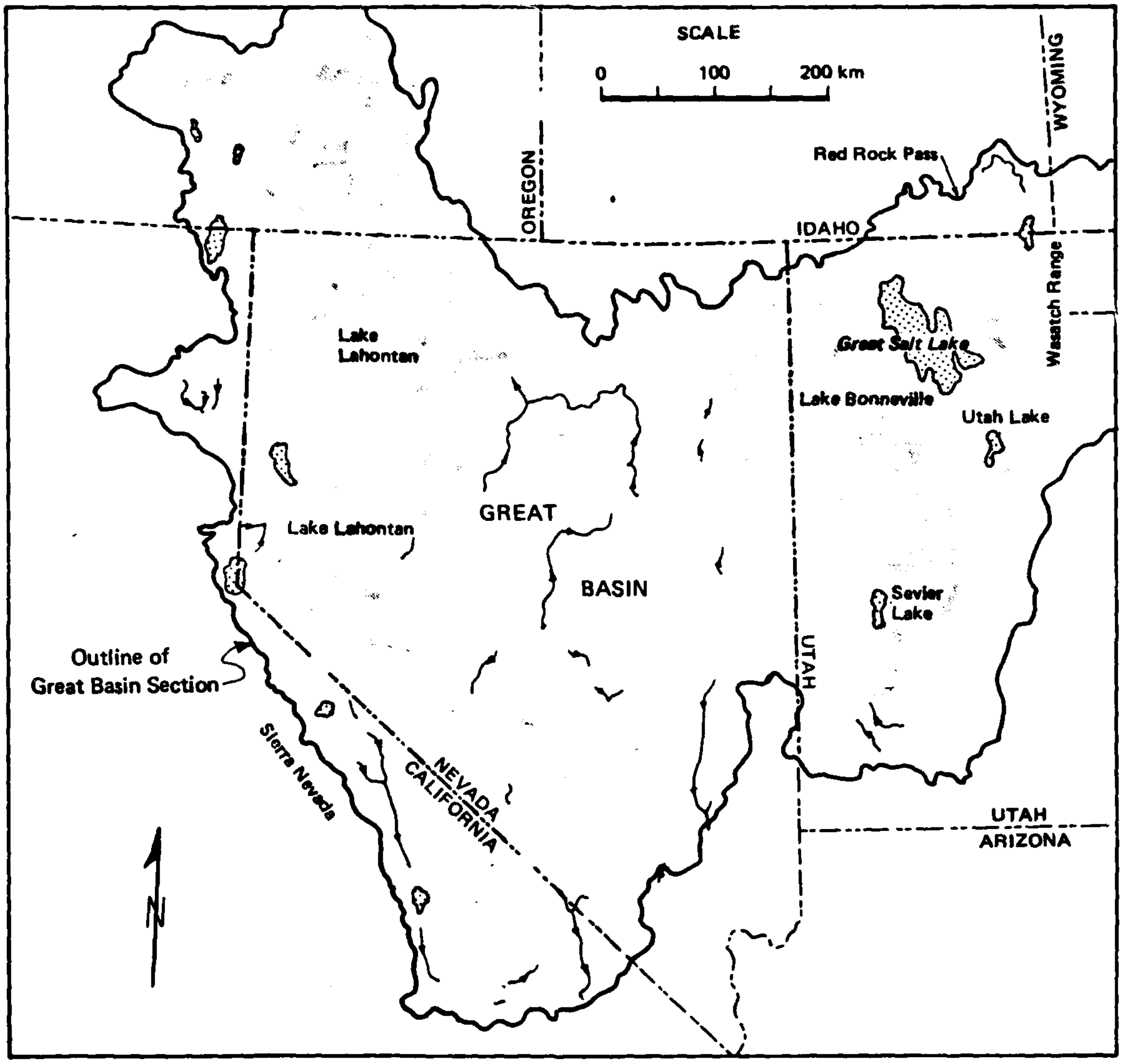
A5i and A5o fans are alluvial surfaces which are no longer receiving sediment and are being degraded and dissected (Figure 5). Since the time their surfaces were abandoned by active drainage systems, soils have formed. A5i fans commonly occupy the majority of the area between the playa or alluvial flat in the center of the valley and the mountain front. A5o fans are distinguished from A5i fans by a lack of flat surfaces in interdrainage divides (Figure 5B) and, in some cases, may contain exhumed caliche beds exposed on the surface. Generally the A5o fans are preserved only where special conditions have allowed the fans to escape complete erosion such as in mountain-valley embayments and in enclosed structural valleys within mountain ranges.

3.5.3 Pluvial-Lake Shoreline Features

An important event for dating faults in the Great Basin was the formation of large lakes from increased precipitation during the cooler climates in Pleistocene time. Most of the large valleys in the Great Basin contained lakes, the largest being

Lake Bonneville in Western Utah and Lake Lahontan in Western Nevada (Figure 6). Ancient Lake Bonneville inundated a large area centered in the present Great Salt Lake Desert west of Salt Lake City, Utah. This large lake included portions of the Sevier Desert, Snake, Wah Wah, Whirlwind, Tule, Dugway, Escalante, and Hamlin MX siting valleys. Ancient Lake Lahontan filled the Carson Sink and numerous adjacent valleys of western Nevada but did not extend into any of the MX siting valleys. However, many of the MX siting valleys in Nevada contained smaller pluvial lakes, including Dry Lake, Lake, Spring, Cave, Garden, Railroad, Little Smoky, Ralston, Jakes, Long, Butte, and Newark valleys. These lakes were not connected to either the Bonneville or Lahontan lakes though they are believed to have formed at the same time because of the geomorphic similarity of their remnant shoreline features to Bonneville Lahontan features and because their formation required climatic conditions similar to that needed for the larger lakes (Mifflin and Wheat, 1979).

The age of the last highstands of Lake Bonneville and Lake Lahontan are not known precisely but most shorelines are believed to have formed during the late stages of the last glacial period (Wisconsin). Morrison (1965) indicated that the age of the highstand was between 11,800 and 15,400 years ago based on radiocarbon dates. Scott (1980) places the last Bonneville highstand at between 12,000 and 20,000 years ago on the basis of recent radiocarbon dates. The highstand of Lake Lahontan has been estimated to have occurred about 12,000 years



After: Putnam, 1978

EXPLANATION

Late Pleistocene lakes

Modern lakes

Arrow indicates stream flow direction between basins

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LATE-PLEISTOCENE LAKES
IN THE GREAT BASIN

FIGURE 6

ago based on carbon-14 dates from a gastropod and tufa near the highstand (dates by M. Rubin in Wallace, 1977). The 12,000 year age may be in error by several thousand years, but falls within the 12,000 to 20,000 years range determined for Lake Bonneville. Shorelines equivalent to early Lahontan and (or) pre-Lahontan shorelines may exist in Diamond, Long, Kobeh, and Newark valleys. Some of these older features may have formed during the previous glacial period (Illinoian) more than about 125,000 years ago (Mifflin and Wheat, 1979). This previous highstand is rarely preserved because its level is about the same as that of the most recent Lahontan highstand.

The highstand of Lake Bonneville can be traced throughout the Utah area by its position as the highest prominent shoreline. In the Cricket Mountain-Escalante Valley area, the highest shoreline is at about 5140 feet (1575 m) and in the Provo area, about 5125 feet (1567 m) (Anderson and Bucknam, 1979; and Anderson, 1980). A younger, well-developed shoreline at 4785 feet (1463 m) in the Provo, Utah, area is referred to as the Provo I shoreline. This shoreline represents the level to which Lake Bonneville fell after it was rapidly drained due to overflow and downcutting through Red Rock Pass in southern Idaho (Gilbert, 1890; and Williams, 1952). The age of the Provo I shoreline is between 9000 and 13,000 years old and is probably closer to 12,000 to 13,000 years old (Bright, 1966; and Scott, 1980). The small pluvial lakes that occupied topographically enclosed valleys in the MX siting region are believed to have reached their highstands at about the same time as Lake Lahontan and Lake Bonneville (Mifflin and Wheat, 1979).

In this report, 15,000 years is used as the best single-age approximation of the last highstands of both Lake Bonneville and Lake Lahontan. This age is chosen to fall between the 12,000 year minimum age estimate of the Provo shoreline and the 20,000 year maximum age estimate of the Bonneville shoreline.

4.0 INTERPRETATIONS

The distribution of faults and lineaments identified during the fault study are shown in Appendix A, Plates A1 through A11. Major faults and lineaments are numbered on Plates A1 through A11 and pertinent physical characteristics and age data are summarized under the corresponding number in Tables A2 and A3 of Appendix A.

4.1 AGE CLASSIFICATION OF FAULTS

The faults and lineaments compiled on Plates A1 through A11 are categorized into four groups; 1) Post Bonneville and Lahontan Pluvial-Lake Highstand, 2) Pleistocene, 3) Indeterminate, and 4) Tectonic Lineament. Because the ages of faults are based primarily on the age of the sediments they displace, it must be understood that the assigned ages represent maximum ages of last movement.

Faults which postdate the Bonneville and Lahontan pluvial-lake highstand are those which displace relatively young features such as young alluvial fans (A5y), Holocene playa deposits (A4), modern stream alluvium (A1), and shorelines and lake deposits correlated with the Bonneville and Lahontan pluvial lakes or their equivalent local lakes (A4o).

Pleistocene faults are between 15,000 years and 1.8 million years old. Late Pleistocene faults are those younger than 700,000 years (the approximate age of the Brunhes-Matuyama magnetic reversal) but older than about 15,000 years. The

Brunhes-Matuyama boundary is the only easily correlatable time horizon within the Pleistocene Epoch. Although no paleomagnetic dating was planned or performed for this investigation, the Brunhes Matuyama boundary was chosen as a dividing line between early and late Pleistocene to accommodate future studies which might involve paleomagnetic dating. Most of the young faults in the study area displace intermediate-age alluvial fans. The well preserved nature of their surface scarps in the generally poorly indurated alluvial materials deposited since the previous pluvial period, the Illinoian, indicates that most faults are considerably younger than 700,000 years. To differentiate between faults that ruptured since the Illinoian stage and those that appear to be older, the term middle Pleistocene is used for some faults. This term is informally used to indicate faults which probably last ruptured the ground surface between about 200,000 and 700,000 years ago.

Early Pleistocene faults are those on which the most recent displacement is younger than about 1.8 million years (the Pliocene-Pleistocene boundary of Berggren, 1971) and older than 700,000 years. Early Pleistocene faults generally occur in the oldest Quaternary alluvial fans (A5o) and volcanic or sedimentary rocks. There are fewer faults in this category than in any other and thus they are grouped with the late Pleistocene features as Pleistocene faults on the accompanying fault maps (Plates A1 through A11).

The indeterminate category was established for well-developed fault scarps which do not occur in surficial Quaternary deposits but are suspected of being Quaternary in age based on:

1. The presence of well-preserved, geomorphically young-looking scarps in bedrock;
2. Location along the contact between bedrock and alluvium, generally at the base of linear mountain fronts;
3. An orientation compatible with typical, late-Tertiary Great Basin fault trends; and
4. Cross-cutting relationships with other faults suspected of being of Quaternary age.

The few conspicuous faults in bedrock included within the Indeterminate age group are generally recognized as bedrock scars, scarps, spring alignments, and prominent vegetation lineaments. The possible importance of bedrock faulting to earthquake and fault-rupture hazards in the MX siting region is exemplified by historic surface ruptures at Fairview Peak, Pleasant Valley, and Excelsior Mountain which exhibit numerous bedrock fractures.

The Tectonic Lineament category includes lineaments that appear to be faults or fault-related cracks such as liquefaction cracks or lurch cracks. Tectonic lineaments are typically strong vegetation alignments, linear tonal contrasts, and other linear features, all without topographic expression. Lineaments in this category are common in the MX siting region and comprise an important group of features in deposits ranging in age from Holocene to early Pleistocene. There are many other tonal contrasts in the study region which may or may not be faults or fault-related features. The more prominent of those features are included as Tectonic Lineaments to be reasonably conservative, whereas, some of the more subtle ones may not be. These relatively arbitrary judgments were based on experience and thus must be considered temporary until final resolution of true origin and age can be verified by trenching.

4.2 DISTRIBUTION AND CHARACTERISTICS OF YOUNG FAULTS

The results of the study show Quaternary faults in every valley studied, although six valleys, Cave, Muleshoe, Hamlin, Pine, Dugway, and Whirlwind have only a few minor faults or lineaments. The last rupture on the vast majority of fault scarps was in the late Quaternary Period (less than about 200,000 years old). Faults with a late Pleistocene age of last rupture are much more numerous in Nevada than in Utah, but only about one-third of the valleys in Nevada have post Bonneville-Lahontan (less than about 15,000 years old) age faults, whereas, about two-thirds of the valleys in Utah have such young faults.

The mapped faults strike primarily north and north-northeast subparallel to the regional structural fabric (Figure 2). They generally comprise linear segments with minor en echelon connecting faults. Although the trends are quite linear when viewed on small-scale maps (1:500,000), in detail (1:62,500), they commonly closely follow the bedrock-alluvium contact. That is, rather than continuing straight, in many cases the faults may trend up valleys and embayments or deviate around faults may trend up valleys and embayments or deviate around bedrock promontories. These deviations are accomplished both by smooth continuous curvilinear faulting and by discontinuous en echelon faulting.

Most scarps are primarily within late-Pleistocene alluvial fans where they form zones of down-to-basin, normal-fault scarps. Many of the major scarps are associated with subparallel shorter scarps with down-to-mountain displacement. Together these two subparallel scarps of opposing sense of displacement form small grabens. The zones of subparallel, and commonly intersecting, scarps and grabens are generally 100 to 500 feet (30 to 150 m) wide but widths up to 3 or 4 miles (about 5 km) are also found.

Several faults which occur at the bedrock-alluvium contact over most of their trace are known to be of late Quaternary age (for example, the Hot Creek-Reveille fault) because of minor displacement of intermediate fans or modern stream channels where the faults cross the mouths of canyons. Commonly, however, channel crossings are characterized only by prominent vegetation alignments without topographic expression. In these cases, judgments were made as to whether these alignments are true fault ruptures or merely linear intensified vegetal growth patterns. Some faults or segments of faults are inferred primarily from alignment of faceted ridge spurs. These are mapped as Indeterminate (probably Quaternary) faults and are believed to signify older Quaternary faults which have not displaced the surface during the last several tens of thousands or perhaps even hundreds of thousands of years.

Numerous faults occur only within bedrock and thus there is no definitive information on their age of last movement other than they must have moved after deposition of the bedrock units they displace. A few of these faults are classified as Indeterminate (probably late Tertiary or Quaternary) because they are represented by more prominent scarps than other bedrock faults and are generally within middle and late Tertiary volcanics. Moreover, parallelism of these faults to other Basin and Range faults and their normal sense of displacement suggest that they are young faults formed during the present Basin-and-Range, block-faulting, tectonic regime. The lack of strong geomorphic expression on some Indeterminate scarps suggests that they have not moved as much or as frequently as the more prominent ones and might suggest that they are no longer potentially active or at least are probably less likely to be reactivated than the younger bedrock-alluvium and alluvial faults. Such faults are mapped because bedrock faults have suffered displacement during historic ruptures in the Fairview Peak, Excelsior Mountain, and Pleasant Valley areas. The 1954 Fairview Peak earthquake, for example, was associated with rupturing of the Gold King fault in the Louderback Mountains which also moved in 1903 (Slemmons and other, 1959). Field reconnaissance also revealed that long segments of the rupture associated with the 1915 Pleasant Valley earthquake were entirely within bedrock. Some of these historic bedrock displacements were so small that it is easy to to imagine that most of the evidence for surface rupture could be removed by erosion within a few thousand years.

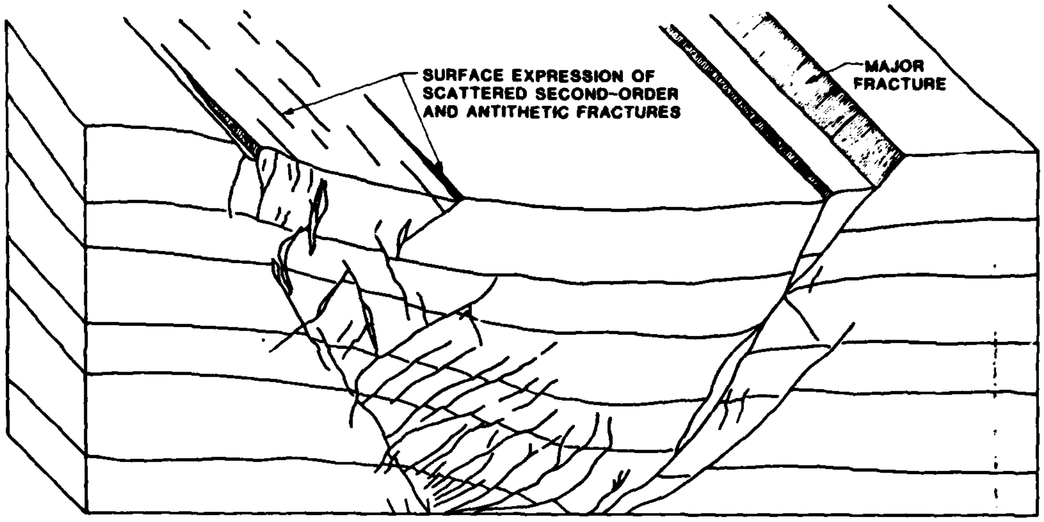
The height and prominence of the alluvial scarps varies greatly from only inches or a few feet with only slightly perceptible changes in slope gradient to high-angle scarps several hundred feet high (for example, the scarps at Empire Canyon along the Hot Creek-Reveille fault zone). The high scarps can generally be shown by geomorphic analysis to be the result of several displacements, but the exact number of movements can not be determined without additional subsurface data. The large majority of alluvial scarps range from about 10 to 50 feet (3 to 15 m) high and, like the higher scarps, also are commonly the result of several movements. Some faults, by the nature of their geomorphic characteristics, appear to be the result of only one or two major displacements (for example, the Dry Lake and Cricket Mountain faults). The Dry Lake scarp is up to about 36 feet (11 m) high along its central reach where two displacements within a short period of time are suspected, but over most of its length, the scarp is 10 to 20 feet (3 to 6 m) high. Based on comparisons to historic surface ruptures (Dixie Valley, Pleasant Valley, Owens Valley), such a scarp could have been caused by one earthquake of magnitude 7 or larger.

Estimates of lengths of major faults and lineament systems are given in Tables A2 and A3. There are several faults with lengths of 30 to 50 miles (50 to 80 km). The longest fault within the study region is the East Railroad Valley fault zone which has a length of about 65 miles (105 km). Other major faults are the Hot Creek-Reveille fault which is 52 miles (84 km) long, the Toiyabe fault which is more than 50 miles (80 km) long, the Egan fault with a length of about 62 miles (100 km), and the North Steptoe Fault which is more than 55 miles (88 km) long. These lengths represent the combination of only the late Pleistocene surface scarps. The greater length of the mountain blocks may indicate that primary subsurface basin-bounding faults are longer. For example, the East Railroad Valley fault system could be as long as 100 miles (160 km), the Toiyabe fault system about 75 miles (120 km) long, and both the North Steptoe-West Steptoe Valley and the Deep Creek-Snake Valley fault systems about 62 miles (100 km) long.

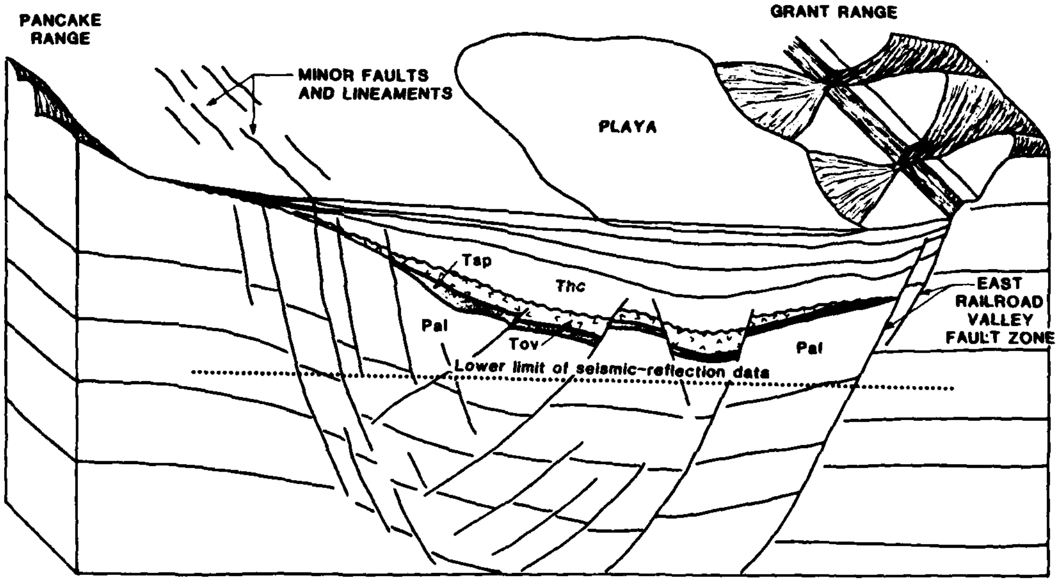
Nearly all of the faults shown on Plates A1 through A11 are normal dip-slip faults. With the exception of low-angle slickensides along the Maynard Lake fault (southern Delamar Valley) and the Kane Springs Wash fault (Coyote-Kane Valley), there is no evidence of strike-slip or even of large components of lateral separation. However, examination of Great-Basin-type normal faults with known lateral components (the Owens Valley, Dixie Valley, and Pleasant Valley faults [Table 1]) suggests that such evidence is rarely pronounced and thus could be very difficult to detect thousands of years after the rupture event. The ubiquitous en echelon fracturing seen throughout the study region may indicate a lateral component of movement associated with dip-slip faulting, but on the local scale, there appears to be no predominance of left-stepping en echelon fracturing over right stepping.

Quaternary surface-fault patterns indicate, and gravity studies confirm, that most of the grabens in the region are asymmetric tilted blocks with a long, large-displacement fault on one side and numerous short, small-displacement faults on the other side and randomly scattered throughout the valley. This conclusion is supported by experimental clay model studies (Cloos, 1968) and seismic-reflection data (Dolly, 1979; and Effimoff and Pinezich, 1980) (Figure 7). At the surface, the major large-displacement faults generally are at the base of or within about 1 mile (1.6 km) of the mountain-front escarpments. Although these long, large-displacement faults generally occur on only one side of a valley (for example, see Hot Creek Valley, Penoyer [Sand Spring] Valley or Dry Lake Valley), in some cases, they may switch from one side of the valley to the other (for example, Railroad Valley).

Figure 8 is a conceptual model of the basic fault-block structure in the study area. This model is based on surface structural patterns within the mountain blocks, young alluvial faults, and gravity studies. The major faults are shown with a constant dip, but our data may not be discriminating enough to rule out the possibility of the faults flattening out at depth (listric faulting) as discussed in Section 2.1. The term "tilt-block" is used in this report because of the tilted nature of the blocks, but others (see discussion in Section



A. CROSS-SECTIONAL SKETCH OF FRACTURE PATTERN IN A BLOCK OF CLAY ON A LATERALLY EXTENDED BASE, AFTER CLOOS, 1968.



B. SIMPLIFIED CROSS-SECTION SKETCH OF SEISMIC-REFLECTION PROFILE ACROSS RAILROAD VALLEY, NEVADA. FAULTS AND STRATA ARE CONTINUED DOWNWARD TO APPROXIMATE RELATIVE PROPORTIONS OF CLAY MODEL.
Thc, Tertiary Horse Camp Formation; Tov, Tertiary Garret Ranch Formation; Tsp, Tertiary Sheep Pass Formation; Pal, Paleozoic carbonates undifferentiated.

NOTE: NOT TO SCALE

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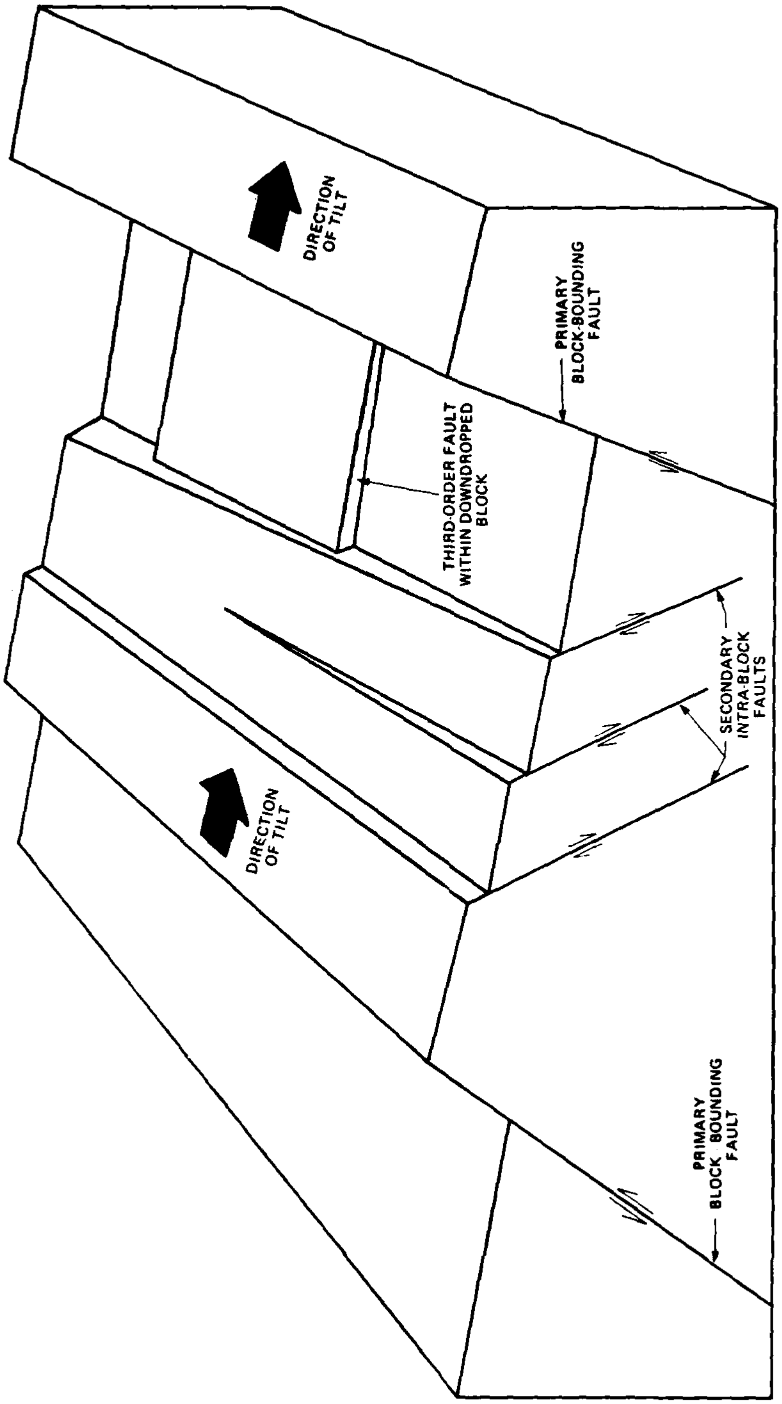
SIMPLIFIED CROSS SECTION OF RAILROAD VALLEY AND COMPARISON TO CLAY MODEL

FIGURE 7



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CONCEPTUAL MODEL OF GREAT BASIN BLOCK FAULTING

FIGURE 8

2.1) may consider this fracture pattern as the horst and graben style. The largest and most important faults with respect to earthquake potential and surface rupture are the primary block-bounding faults. Most structural basins have only one of these and they are the large-displacement features of greatest length and continuity on Plates A1 through A11. The secondary intra-block faults range from small faults and cracks to faults of considerable length and thus in some cases they may also be important earthquake-generating features. The third-order cross faults are shown on Figure 8 only within the central down-dropped block but can occur within any of the blocks. These cross faults are postulated on the basis of gravity anomalies which indicate that several of the longer valleys are underlain by a series of basins separated by topographically high saddles (Fugro National, Inc., 1980b). Although many of these saddles may be flexures, general structural mechanics and regional geologic relationships suggest that some of them probably represent faults. These faults generally terminate against north-south trending faults and can result from inhomogeneity of strain and crustal composition within the crustal blocks. These inhomogeneities may be a result of changes from plastic to brittle behavior of the faulted rocks and (or) may be inherited zones of weakness along the numerous ancient faults which are commonly transverse to the Basin and Range structures. The cross faults may have slight topographic expression or may affect surficial fracture patterns, but they appear to be minor features that are the result, not the cause, of earthquakes and movements along the primary and secondary faults; therefore, generally, they are not believed to represent significant earthquake hazards.

One of the most important pieces of data for understanding the mechanics of block faulting are clay model experiments. Figure 7A is a line drawing of the fracture pattern formed in a block of clay when the base of the block is stretched, presumably similar to the crustal extension of the Great Basin. The major elements of the fracture pattern in the clay block are:

1. One major, relatively simple, down-to-basin fracture on the right side giving a long continuous surface scarp;
2. A complex system of down-to-basin and antithetic fractures on the left side giving a series of short discontinuous cracks and scarps; and
3. Most of the subsurface faults have normal down-to-basin displacements but some displacements show an opposite sense of normal displacement and some show reverse displacements.

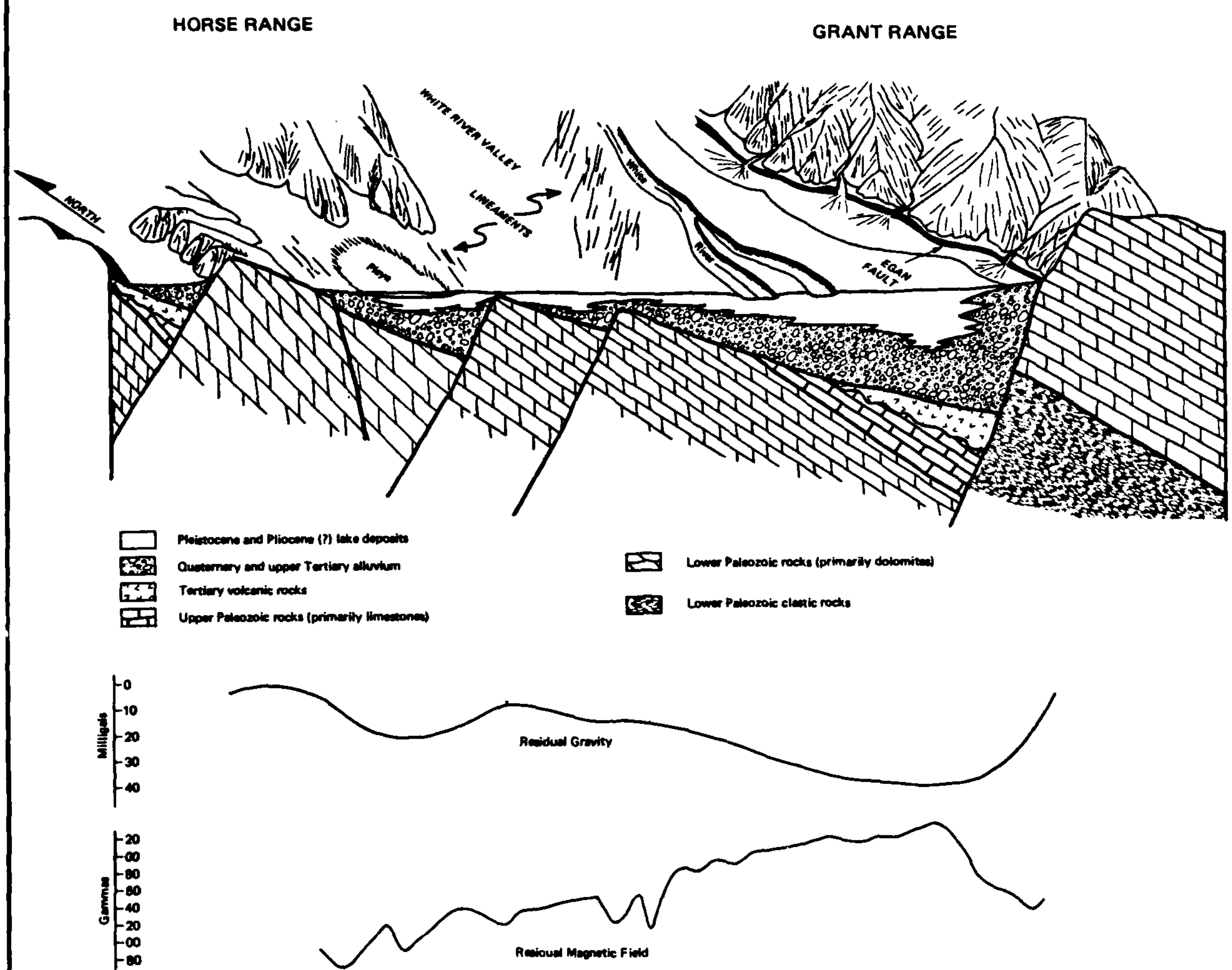
The total extent of the surface pattern is not shown in the illustration but ramping of blocks and transverse failures, as illustrated on Figure 8, also occur.

Figure 7B is a highly simplified block model of an interpretation of a seismic-reflection profile across central Railroad Valley (Dolly, 1978). The major faults, as interpreted from the seismic-reflection record, were extended downward by us and simulated strata were added to the bottom to approximate the relative proportions of the clay model. It is obvious that few additions are needed to nearly duplicate the appearance of the clay-block fracture pattern. The Pancake Range-Railroad

Valley-Grant Range area appears to have a relatively simple tilt-block structure similar to the conceptual model on Figure 8.

White River Valley (Figure 9), the next valley east of the Grant Range, however, is much more complex and is an example of the range of complexity of the fault-block structure in the study region. White River Valley is similar to most valleys in the study region in that it has a major block-bounding fault on one side of the valley and several intermediate intrablock faults on the other side (Plate A6). White River Valley is unusual, however, due to a complex series of northeast-trending features in the center of the valley. On aerial photographs, these features are primarily vegetation alignments generally without topographic relief. Examinations in the field did not reveal many clues to their origin but did suggest some topographic expression. A ground magnetometer survey indicated that some of these features may correlate to minor magnetic anomalies, but the results were inconclusive.

A magnetic traverse across the entire valley, however, revealed significant anomalies which, when combined with gravity information and subsurface projection of bedrock promontories, indicated several subsurface horsts (Figure 9). A major horst is interpreted to underlie the series of features suggesting that they are a result of shallow subsurface movement along secondary intrablock faults and, therefore, these features are interpreted to be faults. The magnetic field increases in



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SIMPLIFIED CROSS SECTION OF
WHITE RIVER VALLEY, NEVADA

FIGURE 9

intensity eastward across the valley corresponding to an opposite trend in gravity. The simplest explanations are 1) that the basin-fill alluvium is highly magnetic, 2) there are subsurface volcanic flows interbedded with the basin-fill, or 3) that volcanics overlie carbonate bedrock below the basin-fill deposits.

There are no volcanic rocks in the exposed blocks in the immediate vicinity of this profile but there are a few, small, scattered outcrops of volcanics on the west side of the valley and much further to the north (see Stewart and Carlson, 1978). This suggests that volcanics may have covered the area prior to inception of the basin and, as block faulting occurred and the basin blocks subsided, were eroded off the top of the exposed blocks but preserved in the subsiding blocks which became protected from erosion by the detritus. The high magnetism, then, may be a result of the presence of these subsurface volcanics, similar to the situation in the adjacent Railroad Valley (Figure 7).

One major observation to evolve from this study is that, with local exceptions, the entire area seems to have undergone similar deformation over the same general time span and at about the same rate. This also appears true for most of the region surrounding the fault-study region. Apparent differences, such as the higher ratio of post-Bonneville-Lahontan to late-Pleistocene-age faults in the eastern Central Great Basin seismotectonic province can be explained in two ways.

A simple explanation of the different ratios would be that faulting has been more active in the eastern region during the latest Pleistocene and Holocene Epochs (that is, during the last 15,000 years). The very nature of the large, structurally deep, Great Salt Lake structural depression suggests that it has a high rate of subsidence which, in conjunction with more abundant and more recent basaltic volcanism, could be a result of greater tectonic activity. The higher rate of seismicity along the eastern edge of the study region in the Intermountain Seismicity Belt may seem to lend credence to this, but may be misleading because that seismic activity is primarily from faults within the Hurricane-Wasatch fault system related to the Great Basin-Colorado Plateau transition. This seismicity may be indicative of the tectonic activity within the Hurricane-Wasatch province and not of tectonism in the eastern Central Great Basin.

An alternative explanation for the higher ratio of post-Bonneville-Lahontan-age scarps in the eastern Central Great Basin is that the late-Pleistocene scarps older than 15,000 years were removed by erosional processes associated with the rise and fall of Lake Bonneville. This explanation is suggested by several lines of evidence. In general, the geomorphic appearance of the valleys in the eastern part of the province which contained Lake Bonneville is much smoother than valleys in the western part of the province which did not host the lake. This suggests that significant erosion and (or) deposition did accompany the Lake. Furthermore, a trench in

Rush Valley, just north of the Sevier Desert deployment area, revealed Quaternary alluvium faulted against older sediments where there was no surface scarp (Everett and Kaliser, 1980) indicating that some Quaternary fault scarps have been removed by erosion. Also, the abundance of linaments in the fine-grained deposits of many valley floors, overlain by shoreline deposits, suggests that these lineaments represent faults which have had their surface scarps removed by erosion or that they are fault-related cracks which were filled by subsequent alluvial and lacustrine deposits. Similar examples of infilled fault fissures and fault-related cracks have been documented in the playas of the Mojave section of the Basin and Range province (Fife, 1980).

4.3 RELATIONSHIP OF QUATERNARY FAULTS TO REGIONAL TECTONIC FEATURES AND LINEAMENT SYSTEMS

4.3.1 Regional Structural Fabric

The tectonic fabric of the study area and surrounding region is illustrated on Figure 2 along with some of the important surrounding tectonic elements. In the broadest sense, this study verifies that the dominant tectonic process in the study area is normal block-faulting in response to east-west or northwest-southeast crustal tension similar to that throughout the remainder of the Central Great Basin. Quaternary faulting within the study region was found to be very similar to other well studied regions in the Central Great Basin province, so the greater density of young faults within the study region apparent on Figure 2 is a result of the study region being subjected to a more-detailed analysis rather than to higher rates of tectonic activity. For example, a portion of the area studied in detail by Wallace (1979) was investigated and found to have young fault scarps and geomorphology comparable to much of the MX siting region.

In spite of the predominance of north-south to northeast-southwest trending normal faults in the Great Basin, major transverse structural lineaments or structural zones have been postulated. Figure 10 shows the extent and location of these lineaments within the Great Basin. Three major groups of lineaments can be distinguished based on orientation; northwest-southeast trending lineaments, northeast-southwest trending lineaments, and east-west trending lineaments.

The northwest-southeast trending lineament group includes Northern Nevada Rift (Mabey, 1966; and Robinson, 1970), the Rye Patch lineament (Rowan and Wetlaufer, 1981), the Walker Lane (Gianella and Callaghan, 1934; Longwell, 1960; Nielsen, 1965; Shawe, 1965; Albers, 1967; and Stewart and others, 1968), and the Las Vegas Shear Zone (Longwell, 1960; Fleck, 1970; and Anderson and others, 1972). The northeast-southwest trending group includes the Midas lineament (Shawe, 1965; and Rowan, 1975) and the Pahranagat Shear Zone (Tschanz and Pampeyan, 1970; Liggett and Ehrenspeck, 1974; and Ekren and others, 1977). The east-west trending group includes the Pritchard Station lineament, the Pancake Range lineament, the Warm Springs lineament, the Timpahute lineament (Ekren and others, 1976), and the Blue Ribbon lineament (Rowley and others, 1978).

Portions of several of these lineaments are within the MX siting region (Figure 10). From north to south these features are Northern Nevada Rift, Pritchards Station, Pancake Range, Warm Springs, Blue Ribbon, and Timpahute lineaments, and the Pahranagat Shear Zone. On the west, portions of the northwest-southeast trending Walker Lane may extend into and through the siting region (Stewart and others, 1968).

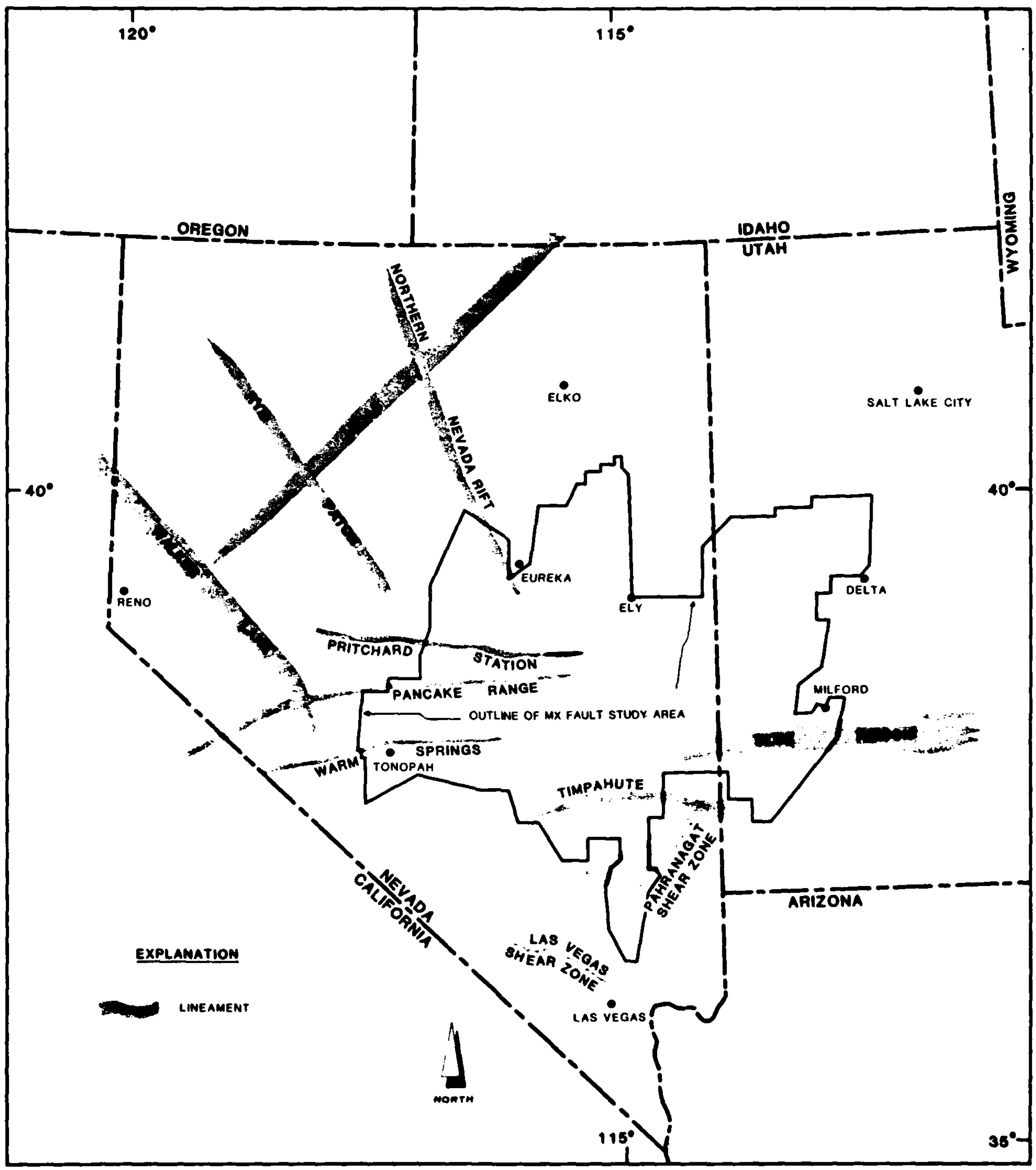
The regional extent of these lineaments is inferred largely from physiographic and tonal features observed on high-altitude aerial photographs and satellite imagery and to a lesser extent from geophysical anomalies. The tectonic features represented by such lineament systems differ greatly in type, age, scale, and geologic significance. Some of these features are unimportant because they are the result of previous tectonic regimes. The regional tectonic lineament systems within the study region were analyzed to determine their relationship to earthquake and fault-rupture hazards.

4.3.2 East-West-Trending Lineament Zones

Analysis of east-west lineament zones shows that if they are true through-going structural features, they are primarily pre-Basin and Range features which do not have a great effect on the present-day block faulting of the region.

A detailed analysis of the Timpahute lineament serves to illustrate the nature of these east-west trending lineament zones. According to Ekren and others (1976) the Timpahute lineament:

1. Controls east-trending mountain ranges and interrupts north-trending valleys and ranges;



SCALE

25 0 25 50 75 100 MILES

25 0 25 50 75 100 KILOMETERS

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MAJOR LINEAMENT SYSTEMS WITHIN AND ADJACENT TO THE MX FAULT–STUDY REGION

FIGURE 10

2. Separates areas of contrasting structural style;
3. Controls the location of intrusive masses;
4. Localizes strike-slip faulting;
5. Is the locus of recent seismicity which does not correlate to mapped structure; and
6. Coincides with a magnetic discontinuity.

Addressing these points individually, it becomes apparent that this lineament zone does not have much significance relative to Basin and Range tectonics. A portion of the lineament coincides with the east-west-trending Timpahute and North Pahroc ranges but the north-south trending Dry Lake Valley and the mountains on the east do not show much evidence for continuation of the lineament to the east.

The termination of the Dry Lake Valley graben in the general vicinity of the lineament appears to be due to vertical tectonics and is not unusual for the Great Basin; at best it would seem to be only permissive evidence for continuation of the lineament. In addition, the Pahroc fault continues across the lineament zone with only minor disruption which appears attributable to normal faulting.

Some of what is cited as contrasting structural styles north and south of the lineament has merit, but these are ancient structural styles. The early Basin-and-Range-age faulting here is of a very special style, termed "thin-skinned distension" by Anderson (1971), and and it is similar on both sides of the lineament. The control of intrusive masses also refers to pre

Basin-and-Range features because none of these intrusives are younger than Miocene. In addition, there are several other similar intrusives in the region that are not within the lineament zone suggesting that this is not a good criterion even for defining pre Basin-and-Range structural zones.

The strike-slip faulting refers to localized faulting along a small part of the western end of the lineament. This strike-slip faulting is both left lateral and right lateral, and pre Basin and Range; other faults suspected by Ekren and others (1976) as being strike-slip faults appear, instead, to be primarily the result of minor amounts of left-separation on normal faults.

The recent seismicity is widely scattered and is not particularly coincident with the lineament. Furthermore, subsequent to publication of the paper describing the lineament, Smith and Lindh (1978) listed a focal mechanism solution from a 4.8 magnitude earthquake (8 December 1971) in the North Pahroc range which yielded a normal-fault solution indicating extension in a N51°W-S51°E direction. This direction of extension is in perfect accordance with pure dip-slip motion on the northeast-southwest-trending normal faults in the epicentral region, in direct contrast to the statement that the earthquakes do not correlate well with mapped structure. The authors mention a magnetic discontinuity but we could not locate any such feature. In addition, our gravity data, although sparse in this region, do not show any major east-west trends.

In summary, there may be some anomalous features in the region of the postulated lineament, but it is difficult to envision a significant structural lineament let alone a young one; any such lineament must be an ancient feature and not important to the present Basin and Range tectonic regime. A younger more prominent lineament zone just south of this feature, the Pahranagat Shear Zone, is discussed in detail below and, as noted there, some of the anomalous features attributed to the Timpahute Lineament may actually be related to the northeast-southwest-trending lineaments. Other postulated east-west trending lineaments were subjected to similar point by point analyses and did not have much evidence to support them being Quaternary features, and therefore we conclude that these features are not important to the earthquake and fault-rupture analysis of the MX deployment region.

4.3.3 Northeast-Southwest Trending Lineament Zones

The Pahranagat Shear Zone, within the southern portion of the study area (Figure 10), was first named and described by Tschanz and Pampeyan (1970) for a series of northeast-southwesterly trending faults. The zone has three major faults, from north to south, these are the Arrowhead Mine fault, Buckhorn fault, and Maynard Lake fault (Table A2, Plate A9). The preliminary work of Tschanz and Pampeyan indicated a combined left-lateral displacement of about 10 miles (16 km) on these three faults. Ekren and others (1977) suggested that the Kane Springs Wash fault, a subparallel northeast-southwest trending fault to the south, is part of the Pahranagat Shear

System with another 5 miles (9 km) of left-lateral displacement.

This study has verified the existence of these faults but uncovered no evidence of Quaternary lateral displacements. The fault zones show abundant low-angle slickensides indicating oblique-slip faulting with large components of lateral movements, but these are all in Miocene rocks. Along the northern three faults there is only one very minor scarp which might be of Quaternary age and this is on the Maynard Lake fault beyond the limits of our high-resolution, color, aerial photographs. Based on analysis of black and white aerial photographs, this scarp appears typical of colluvium-covered bedrock pediments and therefore may only appear to be a scarp in Quaternary alluvium. Because this scarp was not field checked, it is conservatively assumed to indicate Quaternary rupture of the Maynard Lake Fault, but it indicates only dip-slip separation. The Kane Springs Wash fault has abundant evidence of late-Pleistocene separation but, similar to the Maynard Lake fault, only dip-slip separation has been documented. Thus the Quaternary displacement history of faults in the Pahranagat Shear System appears to be typical of the Great Basin, that is, they are basin-bounding faults with normal dip-slip displacement.

The total amount of left-lateral displacement on the system is uncertain. Some of the 10 miles (16 km) of postulated displacement on the northern faults can be attributed to normal separation. To achieve the separation indicated by the offset beds on the west side of Pahranagat Valley by only dip-slip motion, however, would require several miles of vertical displacement which is doubtful. However, on the east side of the valley, a distinctive late-Tertiary basalt interbed could be interpreted to show less than 1 mile (1.6 km) of separation along the Maynard Lake fault, an amount that can be accommodated by dipslip displacement.

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A tight cluster of small earthquake activity occurred in the vicinity of the Pahranagat Shear System in 1979. The aerial photographs used in this study had been flown prior to these earthquakes so they are of no help in locating any possible surface ruptures. Limited field reconnaissance did not indicate any surface ruptures in the epicentral area. The abundance and relative youthfulness of normal faulting in this area indicate that it is very likely that this activity could have been related to Basin-and-Range-type normal faulting and thus does not necessarily indicate that the system is seismically active.

Although the case for large lateral displacement on the Pahranagat Shear System is marred with uncertainties, these normal faults do appear to have been involved in some type of shearing tectonics. Ligget and Ehrenspeck (1974) postulated that the Pahranagat Shear System was an intra-continental transform fault between east-west extending grabens. This interpretation seems to fit the structural relationships well, including the "thin-skin distension" style of faulting, and explains the abrupt termination of the system on the east and west.

The similarity and alignment of the faults in the Pahranagat Shear System to small faults in the Nevada Test Site such as the Cane Spring and Rock Valley faults (Figure 2) was noted in the Interim Fault Study Report (Fugro National, Inc., 1930a) and in that report, the possibility of a through-going interconnection was considered. Subsequent aerial-photograph and field analysis indicates that these groups of faults are clearly separated by prominent late Quaternary northerly trending faults, and there is no direct connection or through-going fault system.

Our investigation uncovered other faults in this region which are subparallel to faults in the Pahranagat Shear System. At

the north end of Sixmile Flat (Pahroc Valley), several small Quaternary faults show minor left separation, but the faults are bounded on both ends by north-south trending normal faults indicating that the separation is primarily due to normal displacement (Plate A9). In the southern part of Coyote Spring Valley (Plate A11), the Transector fault also is parallel to the Pahranagat faults but has only normal separation. This fault is also bounded by north-south trending normal faults and thus appears to be a member of the northeast-southwest trending basin-bounding faults typical, except for orientation, of the Great Basin. In California Wash, just south of the study area, (Drawing A11) this same pattern of Quaternary faulting persists
(Drawing A11) this same pattern of Quaternary faulting persists
(Schell and Wilson, 1981). Other northeast-southwest trending faults, just north of Lake Mead with about 40 miles (65 km) of left-lateral Miocene displacement, have been described by Anderson (1973) and Bohannon (1979). This Lake Mead fault system terminates in an area of "thin-skin distension" similar to the Pahranagat system suggesting similar mechanisms.

In general terms, the pattern of Quaternary faulting between the Penoyer fault on the north to at least the California Wash fault and perhaps to the Lake Mead fault zone (not shown) is one of predominantly north-south trending faults which curve southwesterly at their southern ends. These faults are associated with abundant northerly trending faults, and only normal separation has been documented in Quaternary units. This area of southern Nevada is the locus of small- to moderate-magnitude earthquake activity which appears to represent a higher rate of activity than the remainder of the Great Basin to the north (except the Dixie Valley-Pleasant Valley zone). These earthquakes form a broad belt extending southwesterly into Nevada from the Escalante Desert-Cedar City, Utah, area. The southwesterly extent of the seismic belt is unknown because of the abundant nuclear testing activity in the Nevada Test Site which obscures the natural earthquake activity. Even though the nuclear tests could be identified in the earthquake catalog, the small aftershocks associated with these tests are difficult to differentiate from the small-magnitude natural earthquakes, and any tectonic interpretation would be speculation.

The above discussion seems to indicate a pattern unique to southern Nevada, that this part of Nevada, in contrast to the rest of the Great Basin, has an abundance of northeast-southwest trending faults. The left-lateral strike-slip nature of this faulting has been emphasized (Slemmons, 1967; Tschanz and Pampeyan, 1970; Anderson, 1973; and Bohannon, 1979) but appears to be primarily a pre Basin-and-Range phenomenon. Any lateral displacements contemporaneous with Basin and Range normal faulting are very minor and probably significant only as minor adjustments along favorably oriented zones of weakness from previous tectonic regimes. The coincidence of these tectonic features with the southwestern branch of the Intermountain Seismic Belt and geophysical anomalies (P-wave anomalies, gravity anomalies), and a belt of late Tertiary (17 to 6 million years) volcanics led Schell (1978) and Schell and Wilson (1981) to separate this corridor from the Central Great Basin seismotectonic province and establish the Southern Nevada seismotectonic province (Figure 3). Greensfelder and others (1980) isolated the northern part of this corridor but emphasized its left-lateral faulting aspects and characterized it as continuous with the Garlock fault in California, a hypothesis that seems highly unlikely because of the overwhelming prominence of northerly and northeasterly trending Quaternary dip-slip faulting throughout the region.

4.3.4 Northwest-Southeast Trending Lineament Zones

The Walker Lane is the name given to a belt of topographic lows extending southeasterly from northeastern California through Soda Springs Valley (Figures 2 and 10). This belt is quite prominent on Landsat imagery and regional fault maps because it represents a zone of discontinuity between northeasterly trending fault blocks to the east and northwesterly trending fault blocks on the west. The zone is weakly represented on regional gravity maps and aeromagnetic maps. The feature was recognized by Gianella and Callaghan (1934) and by Locke and others (1940) and has been regarded as a zone of right-lateral shear faulting although lateral displacements are presently known in only two places, possibly near Honey Lake at its northwestern end (Bell and Slemmons, 1979) and in Soda Springs Valley at its southeastern end (Hardyman and others, 1975). Based on regional stratigraphic relationships, Albers (1967) and Stewart and others (1968) postulated from 80 to 120 miles (130 to 200 km) of right-lateral displacement on a structural zone comprising the Walker Lane, Las Vegas Valley Shear Zone, and the Death Valley-Furnace Creek fault zone. Most of this displacement, however, is accounted for by the Las Vegas and Furnace Creek-Death Valley zones. The major displacement in the Walker Lane is within the Soda Spring Valley fault system which has about 30 miles (48 km) of right-lateral displacement, some of late-Quaternary age, distributed over five faults (Ekren and others, 1976).

If the Walker Lane connects with the Las Vegas Valley Shear Zone, as has frequently been suggested, it would pass through the central to southern portion of Big Smoky Valley. The southeasternmost extent of Quaternary faulting in the Walker Lane is the Soda Springs Valley fault about 20 miles (32 km) northwest of Big Smoky Valley. Quaternary faults in Big Smoky Valley which trend across this projection appear to be typical northerly striking Basin-and-Range-type normal faults, although some of them do trend more easterly of north than most faults in the Great Basin. Gravity data (Fugro National, Inc., 1980c) indicated complex structure in the subsurface below Big Smoky Valley but, like the surface faults, the structural trends seemed to maintain a northerly orientation compatible with typical Great Basin trends. Much of the area between the southern end of the Soda Springs Valley fault and the Black Mountain volcanic center (area between 37° and 38°) at the northern end of the Las Vegas Valley Shear Zone is typified by Quaternary and late Tertiary structural trends which trend more northeasterly than is typical of the Great Basin. Albers

(1967) characterized this area as a belt of sigmoidal bending or an oroflex. Northwest-southeast trending structures dominate again further to the west in Fish Lake Valley along the Furnace Creek fault zone. The lack of structural continuity between the Walker Lane and Las Vegas Valley Shear Zone and evidence that most of the lateral movement occurred within Miocene time (Nielsen, 1965; Fleck, 1970; Anderson and others, 1972; Bohannon, 1979) suggest that presently there is no connection between the Walker Lane and Las Vegas Valley Shear Zone. Under the present tectonic regime the connection is probably between the Walker Lane and the Furnace Creek zone (Schell and Hileman, 1979; and Greensfelder and others, 1980).

The Las Vegas Valley shear zone is the name given to the zone of deformation between the mountains on each side of Las Vegas Valley (Longwell, 1960). Paleozoic rocks and Mesozoic-age folds and thrust faults appear bent so as to indicate right-lateral shift of about 20 to 42 miles (32 to 68 km) (Stewart and others, 1968). Most, if not all, of this offset and folding transpired prior to late Miocene time (more than 11 million years ago) (Fleck, 1970; Anderson and others, 1972; and Bohannon, 1979). The feature has been postulated to extend northwesterly to link up with the Walker Lane but, as described above, there is little evidence of any present-day relationship between this ancient feature and the Walker Lane.

The Northern Nevada Rift (Figure 10) discussed by Zoback and Thompson (1978), also named the Cortez Rift by Mabey and others

(1978), extends to about the northern edge of the fault study area. This feature was initially delineated on the basis of a distinct zone of north-northwest aligned positive magnetic anomalies (Mabey, 1966; and Robinson, 1970) which are related to a linear mafic dike swarm. This magnetic anomaly is produced by Miocene basalt dikes and related flows and, in part, by a deeper, presumably related, dikelike mass (Robinson, 1970). Toward the south, the anomaly narrows and terminates adjacent to the northern portion of the MX deployment area in the vicinity of the Roberts Mountains. The feature is believed to be an ancient rift system formed under a differently oriented (N68°E-S68°W) stress field (Zoback and Thompson; 1978) that no longer plays a role in Great Basin tectonics.

4.4 EARTHQUAKE AND FAULT RUPTURE HAZARDS

4.4.1 General Discussion

The geologic data show that faults have ruptured in nearly every valley within late Quaternary time (about the last 200,000 years) and most have ruptured more than once during this time interval. To assess earthquake and fault-rupture hazards, the frequency of these fault ruptures (recurrence interval) must be known. This information can only be obtained under very ideal conditions where there are several displaced features of known age. Absolute-age information on faulting in the Great Basin is very limited; the only dated young features are the Bonneville and Lahontan shorelines and some late-Cenozoic rock formations. The time between these dated materials is commonly a few million years, therefore, recurrence intervals are very imprecise and amount to nothing more than statements such as "two to five movements in late Quaternary time." More precise determinations must await trenching investigations and absolute age-dating. In the mean-time, only broad ranges of the age of fault displacements and major earthquakes can be approximated.

4.4.2 Maximum Earthquake

Geomorphic characteristics observed throughout the Great Basin suggest that major ruptures and hence large earthquakes have occurred at numerous places during late Quaternary time. This conclusion is based on the abundance of long faults with large scarps. The relationship between fault length, fault displacement, and earthquake magnitude have been widely discussed (Tocher, 1958; Iida, 1959, 1965; Albee and Smith, 1966; Bonilla, 1967, 1970; King and Knopoff, 1969; Slemmons, 1977; and numerous others). Homogeneous geomorphic characteristics along certain faults in the study area indicate that several of the major faults may have had surface ruptures with lengths in the 50- to 60-mile (80- to 100-km) range which suggests that earthquakes in the 7- to 7-3/4-magnitude range, similar to those associated with historic ruptures northwest of the siting region, have occurred (Table 1).

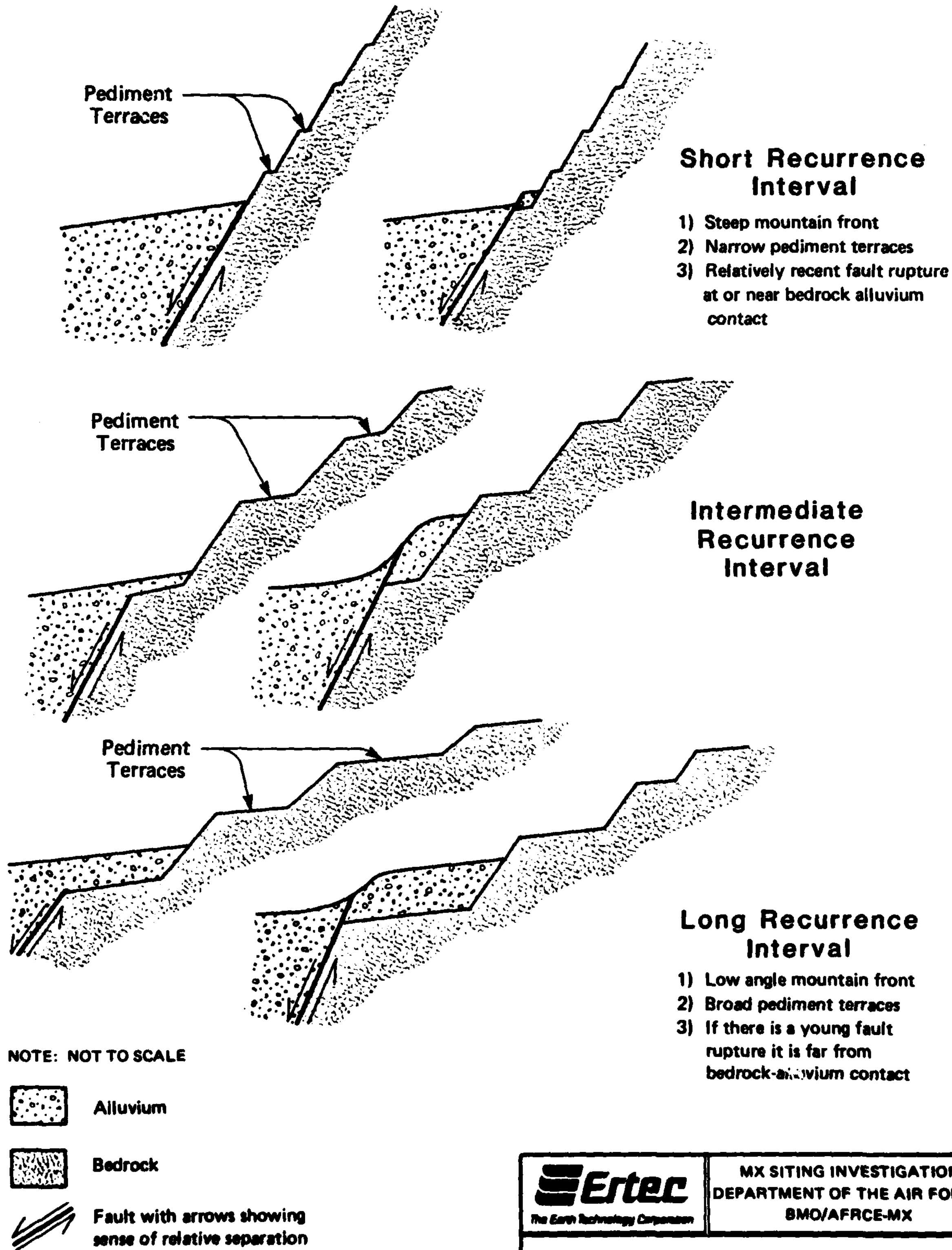
4.4.3 Earthquake Recurrence Intervals

The frequency with which these large earthquakes occur on the same fault is difficult to determine because of the limited age information. Based on geomorphic parameters, it appears that some faults have shorter recurrence intervals than others. This conclusion is based on such factors as 1) the Dry Lake fault scarp, one of the younger major scarps, appears to have moved within the last few thousand years but does not appear to have moved during a major event in the prior 200,000 (+) years, and 2) the geomorphic characteristics of the Hot Creek-Reveille fault system, in contrast, indicate numerous displacements within about the same time interval including within the last few thousand years, and possibly within Holocene time (McKeown and Dickey, 1969).

An example of an alluvial fan complex which enables approximation of recurrence intervals occurs along the Hot Creek fault near Empire Canyon; an old (A5o) fan has about a 440-foot (134-m)-high scarp; an older intermediate-age fan (A5i) has a scarp of more than 200 feet (60 m); a younger intermediate-age fan (A5i) has about a 90-foot- (27-m) high scarp, still younger fluvial terraces have about a 35-foot- (11-m) high scarp; and young-age (A5y) fans and modern stream channels do not show any displacement.

The declivity of mountain fronts may also provide some insight into the frequency of earthquakes (Hamlin, 1976; and Wallace, 1977). Allowing for differences in rates of erosion due to rock type and lack of knowledge about slope-forming processes, some mountain fronts appear to be steeper, more linear, and in general, have less evidence of prolonged erosion (Narrow v-shaped canyons, few well-developed terraces or benches, sharper ridge crests, less dissected ridge-spur facets, etc.).

The steep mountain fronts are commonly unterraced suggesting that the time between fault displacements has been too short to allow these erosional surfaces to develop (Figure 11). The faulted mountain fronts with longer recurrence intervals accordingly have these pediment terraces and hence lower slope angles. A similar concept involves the distance between alluvial scarps and the bedrock-alluvium contact. If faulting events are closely spaced in time, there will not be enough time for the bedrock to be eroded back and hence the fault scarps are at or near the present bedrock-alluvium contact (Figure 11). On the other hand, if a long time has elapsed between major faulting events, a wide terrace or gap between the alluvial scarp and the mountain front will develop. Based on these principles, it appears that faults such as the Dry Lake, Snake Valley, and Southern Spring Valley faults last ruptured within very late-Quaternary time but had not moved very frequently during the preceding late-Quaternary time period. In contrast to these faults with very long recurrence intervals, faults such as the Egan (White River Valley) and Railroad Valley faults with alluvial scarps only a short distance from steep mountain fronts have intermediate-length recurrence intervals, and faults such as the Hot Creek-Reveille fault with scarps very near or right at steep mountain fronts have relatively short recurrence intervals. There is very little information on the quantitative aspects of terms such as "long", "intermediate," and "short" as used above except that even the short ones are of the same order of length as the post



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RELATIONSHIP OF MOUNTAIN FRONT DECLIVITY TO FAULT RECURRENCE INTERVALS

FIGURE 11

Bonneville-Lahontan time interval, that is about 15,000 years long.

A synthesis of the published recurrence intervals for the Great Basin area, indicates that an approximate estimate of the average recurrence interval is some ere between about 6000 years and several tens of thousands of years. Some short-term recurrences as low as 1000 to 2000 years may occur (or even tens of years in the zone of historic ruptures), and some as long as several hundred thousand years are also suggested, but most of these areas have not been studied in enough detail to make definite assertions. Such long recurrence intervals are in accord with Wallace (1977) who noted that large earthquakes appear to cluster in both space and time and with Ryall (1977) who saw a cycle in the seismic patterns. These points are very important for earthquake hazards assessments in the Great Basin because they indicate that all Quaternary faults probably have a potential to generate earthquakes under the present tectonic regime.

4.4.4 Areas Susceptible to Surface Fault Rupture

Surface rupture during future earthquakes is likely along any of the Quaternary faults (Plates A1 through A11). In general, the areas near the mountain fronts appear most susceptible to surface ruptures but even some of the playas have experienced ground rupture. Furthermore, any of the playa areas where shallow ground water occurs have an increased potential for earthquake-related phenomena such as lurch cracking and liquefaction.

Nearly all of the faults in the study area are down-to-basin normal faults. Such faults are typified by one major break on the upslope side (nearest the mountain) and a minor antithetic break downslope (Figure 4). These faults typically form a small narrow graben which is characterized by numerous small fractures and general loss of ground stability within the graben. Also, small faults commonly occur basinward of the graben in zones up to several hundred feet wide.

Based on these fault characteristics, engineered structures can be located much closer to the upslope side of the main fault than to the downslope side. Because of the wide variety of characteristics, it is not practical to establish a general setback distance which covers all cases, so each fault was considered separately. Preliminary shelter locations were situated so as to avoid faults but roads were allowed to cross some faults and lineaments because it is generally infeasible, if not impossible, to avoid them completely. Disruption of these roads by ground-surface rupture should not pose a great safety hazard nor significantly impact operation of the MX system because repair could be accomplished within a matter of hours after the rupture.

The ground-rupture hazard in the vicinity of the playas is difficult to analyze because the hydrologic processes in these regions tend to obliterate all but the largest surface fractures very rapidly. The 1934 Hansel Valley earthquake of magnitude 6.6 (Figure 2 and Table 1) which occurred in the middle portion of Hansel Valley, Utah, provides historical evidence that these areas are susceptible to surface rupture. Teels Marsh, a playa near the 1932 Cedar Mountain earthquake, experienced cracking during that earthquake. However, most of the playa areas are excluded from consideration as potential shelter locations due to the shallow ground water and poor soil conditions. The margins of playas and the alluvial flats, however, may be suitable and thus determination of the origin of the numerous lineaments (Section 4.1) which occur in these areas is important. The major lineament zones (Table A3) and lineaments between known fault segments should be avoided because these lineaments may well be related to faulting. Individual or isolated lineaments may be another matter; until trenching studies are conducted to determine the nature of these lineaments, we recommend that they be avoided. However, it seems probable that some of these areas may be suitable because some lineaments may be only dessication cracks or only indirectly related to faulting such as post-earthquake settlement crakcs. If so, they could be a one-time only feature; future earthquakes might cause cracking in the same general area but may not coincide with exactly the same crack.

5.0 CONCLUSIONS

Major conclusions derived from the fault study are:

- o Every valley in the MX deployment area has faults that have been active in Quaternary time;
- o Quaternary faults generally are parallel to the regional Great Basin structural fabric which is oriented north-south or northeast-southwest;
- o Quaternary faults are almost exclusively normal faults;
- o Basins are primarily asymmetric grabens or tilt blocks which vary from one simple tilt-block structure to multiple en echelon tilt blocks;
- o Most grabens or tilt-block systems have only one major block-bounding fault;
- o Large earthquakes (7 to 7 3/4) have occurred in the study area during late Quaternary time and are capable of occurring again on the major block-bounding faults;
- o The time interval between large earthquakes is several thousand years long and probably averages on the order of more than 15,000 years; and
- o Fault-rupture hazards are greatest near the mountain fronts but also are present near the centers of some valleys.

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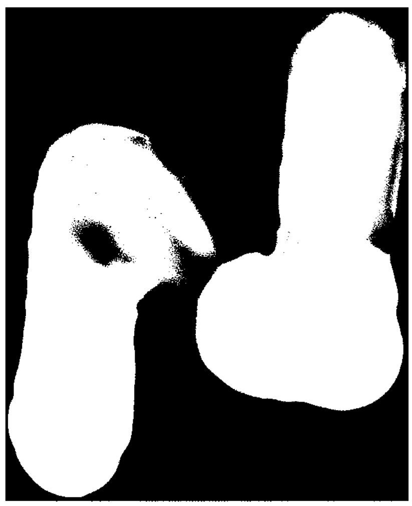

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